Post-Construction Storm Water Management in New Development and Redevelopment

Regulatory Text

- You must develop, implement, and enforce a program to address storm water runoff from new development and redevelopment projects that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, that discharge into your small MS4. Your program must ensure that controls are in place that would prevent or minimize water quality impacts.
- You must:
    - Develop and implement strategies which include a combination of structural and/or non-structural best management practices (BMPs) appropriate for your community;
    - Use an ordinance or other regulatory mechanism to address post-construction runoff from new development and redevelopment projects to the extent allowable under State, Tribal or local law;
    - Ensure adequate long-term operation and maintenance of BMPs.

Guidance

If water quality impacts are considered from the beginning stages of a project, new development and potentially redevelopment provide more opportunities for water quality protection. EPA recommends that the BMPs chosen: be appropriate for the local community; minimize water quality impacts; and attempt to maintain pre-development runoff conditions. In choosing appropriate BMPs, EPA encourages you to participate in locally-based watershed planning efforts which attempt to involve a diverse group of stakeholders including interested citizens. When developing a program that is consistent with this measure's intent, EPA recommends that you adopt a planning process that identifies the municipality's program goals (e.g., minimize water quality impacts resulting from post-construction runoff from new development and redevelopment), implementation strategies (e.g., adopt a combination of structural and/or non-structural BMPs), operation and maintenance policies and procedures, and enforcement procedures. In developing your program, you should consider assessing existing ordinances, policies, programs and studies that address storm water runoff quality. In addition to assessing these existing documents and programs, you should provide opportunities to the public to participate in the development of the program. Non-structural BMPs are preventative actions that involve management and source controls such as: policies and ordinances that provide requirements and standards to direct growth to identified areas, protect sensitive areas such as wetlands and riparian areas, maintain and/or increase open space (including a dedicated funding source for open space acquisition), provide buffers along sensitive water bodies, minimize impervious surfaces, and minimize disturbance of soils and vegetation; policies or ordinances that encourage infill development in higher density urban areas, and areas with existing infrastructure; education programs for developers and the public about project designs that minimize water quality impacts; and measures such as minimization of percent impervious area after development and minimization of directly connected impervious areas. Structural BMPs include: storage practices such as wet ponds and extended-detention outlet structures; filtration practices such as grassed swales, sand filters and filter strips; and infiltration practices such as infiltration basins and infiltration trenches. EPA recommends that you ensure the appropriate implementation of the structural BMPs by considering some or all of the following: pre-construction review of BMP designs; inspections during construction to verify BMPs are built as designed; post-construction inspection and maintenance of BMPs; and penalty provisions for the noncompliance with design, construction or operation and maintenance. Storm water technologies are constantly being improved, and EPA recommends that your requirements be responsive to these changes, developments or improvements in control technologies.

BMP Fact Sheets

Structural BMPs

Ponds

Dry extended detention ponds

Wet ponds

Infiltration practices

Infiltration basin

Infiltration trench

Porous pavement

Filtration practices

Bioretention

Sand and organic filters

Vegetative practices

Storm water wetland

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Grassed filter strip

Runoff pretreatment practices

Catch basin

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Better site design

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BMP inspection and maintenance

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Additional Fact Sheets

Bioretention

Hydrodynamic Separators

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Modular Treatment System

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Structural BMPs

Ponds

Dry Extended Detention Pond

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Dry extended detention ponds (a.k.a. dry ponds, extended detention basins, detention ponds, extended detention ponds) are basins whose outlets have been designed to detain the storm water runoff from a water quality design storm for some minimum time (e.g., 24 hours) to allow particles and associated pollutants to settle. Unlike wet ponds, these facilities do not have a large permanent pool. However, they are often designed with small pools at the inlet and outlet of the basin. They can also be used to provide flood control by including additional flood detention storage.

A dry extended detention pond is designed to temporarily detain runoff during storm events

Applicability

Dry extended detention ponds are among the most widely applicable storm water management practices. Although they have limited applicability in highly urbanized settings, they have few other restrictions.

Regional Applicability

Dry extended detention ponds can be applied in all regions of the United States. Some minor design modifications might be needed, however, in cold or arid climates or in regions with karst (i.e. limestone) topography.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface is present. It is difficult to use dry extended detention ponds in the ultra-urban environment because of the land area each pond consumes. They can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the pond.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. Dry extended detention ponds can accept runoff from storm water hot spots, but they need significant separation from ground water if they will be used for this purpose.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Dry extended detention ponds are very useful storm water retrofits, and they have two primary applications as a retrofit design. In many communities in the past, detention basins have been designed for flood control. It is possible to modify these facilities to incorporate features that encourage water quality control and/or channel protection. It is also possible to construct new dry ponds in open areas of a watershed to capture existing drainage.

Cold Water (Trout) Streams

A study in Prince George's County, Maryland, found that storm water management practices can increase stream temperatures (Galli, 1990). Overall, dry extended detention ponds increased temperature by about 5°F. In cold water streams, dry ponds should be designed to detain storm water for a relatively short time (i.e., less than 12 hours) to minimize the amount of warming that occurs in the practice.

Siting and Design Considerations

Siting Considerations

Although dry extended detention ponds can be applied rather broadly, designers need to ensure that they are feasible at the site in question. This section provides basic guidelines for siting dry extended detention ponds.

<u>Drainage Area</u>

In general, dry extended detention ponds should be used on sites with a minimum area of 10 acres. On smaller sites, it can be challenging to provide channel or water quality control because the orifice diameter at the outlet needed to control relatively small storms becomes very small and thus prone to clogging. In addition, it is generally more cost-effective to control larger drainage areas due to the economies of scale (see Cost Considerations).

<u>Slope</u>

Dry extended detention basins can be used on sites with slopes up to about 15 percent. The local slope needs to be relatively flat, however, to maintain reasonably flat side slopes in the practice. There is no minimum slope requirement, but there does need to be enough elevation drop from the pond inlet to the pond outlet to ensure that flow can move through the system.

<u>Soils / Topography</u>

Extended detention basins can be used with almost all soils and geology, with minor design adjustments for regions of karst topography or in rapidly percolating soils such as sand. In these areas, extended detention ponds should be designed with an impermeable liner to prevent ground water contamination or sinkhole formation.

Ground Water

Except for the case of hot spot runoff, the only consideration regarding ground water is that the base of the extended detention facility should not intersect the ground water table. A permanently wet bottom may become a mosquito breeding ground. Research in Southwest Florida (Santana et al., 1994) demonstrated that intermittently flooded systems, such as dry extended detention ponds, produce more mosquitoes than other pond systems, particularly when the facilities remained wet for more than 3 days following heavy rainfall.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. Some features, however, should be incorporated into most dry extended detention pond designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay, which is a small pool (typically about 10 percent of the volume of water to be treated for pollutant removal).

Treatment

Treatment design features help enhance the ability of a storm water management practice to remove pollutants. Designing dry ponds with a high length-to-width ratio (i.e., at least 1.5:1) and incorporating other design features to maximize the flow path effectively increases the detention time in the system by eliminating the potential of flow to short-circuit the pond. Designing ponds with relatively flat side slopes can also help to lengthen the effective flow path. Finally, the pond should be sized to detain the volume of runoff to be treated for between 12 and 48 hours.

Conveyance

Conveyance of storm water runoff into and through a storm water management practice is a critical component of any such practice. Storm water should be conveyed to and from practices safely in a manner that minimizes erosion potential. The outfall of pond systems should always be stabilized to prevent scour. To convey low flows through the system, designers should provide a pilot channel. A pilot channel is a surface channel that should be used to convey low flows through the pond. In addition, an emergency spillway should be provided to safely convey large flood events. To help mitigate warming at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In dry extended detention ponds, a "micropool" at the outlet can prevent resuspension of sediment and outlet clogging. A good design includes maintenance access to the forebay and micropool.

Another design feature that can reduce maintenance needs is a non-clogging outlet. Typical examples include a reverse-slope pipe or a weir outlet with a trash rack. A reverse slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and determines the water elevation of the micropool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris.

Landscaping

Designers should maintain a vegetated buffer around the pond and should select plants within the extended detention zone (i.e., the portion of the pond up to the elevation where storm water is detained) that can withstand both wet and dry periods. The side slopes of dry ponds should be relatively flat to reduce safety risks.

Design Variations

Dry Detention Ponds

Dry detention ponds are similar in design to extended detention ponds, except that they do not incorporate features to improve water quality. In particular, these practices do not detain storm water from small-flow events. Therefore, detention ponds provide almost no pollutant removal. However, dry ponds can help to meet flood control, and sometimes channel protection, objectives in a watershed.

Tank Storage

Another variation of the dry detention pond design is the use of tank storage. In these designs, storm water runoff is conveyed to large storage tanks or vaults underground. This practice is most often used in the ultra-urban environment, on small sites where no other opportunity is available to provide flood control. Tank storage is provided on small areas because providing underground storage for a large drainage area would generally be cost-prohibitive. Because the drainage area contributing to tank storage is typically small, the outlet diameter needed to reduce the flow from very small storms would very small. A very small outlet diameter, along with the underground location of the tanks, creates the potential for debris being caught in the outlet and resulting maintenance problems. Since it is necessary to control small runoff events (such as the runoff from a 1-inch storm) to improve water quality, it is generally infeasible to use tank storage for water quality and generally impractical to use it to protect stream channels.

Regional Variations

Arid or Semi-Arid Climates

In arid and semi-arid regions, some modifications might be needed to conserve scarce water resources. Any landscaping plans should prescribe drought-tolerant vegetation wherever possible. In addition, the wet forebay can be replaced with an alternative dry pretreatment, such as a detention cell. One opportunity in regions with a distinct wet and dry season, as in many arid regions, is to use regional extended detention ponds as a recreation area such as a ball field during the dry season.

Cold Climates

In cold climates, some additional design features can help to treat the spring snowmelt. One such modification is to increase the volume available for detention to help treat this relatively large runoff event. In some cases, dry facilities may be an option as a snow storage facility to promote some treatment of plowed snow. If a pond is used to treat road runoff or is used for snow storage, landscaping should incorporate salt-tolerant species. Finally, sediment might need to be removed from the forebay more frequently than in warmer climates (see Maintenance Considerations for guidelines) to account for sediment deposited as a result of road sanding.

Limitations

Although dry extended detention ponds are widely applicable, they have some limitations that might make other storm water management options preferable:

- Dry extended detention ponds have only moderate pollutant removal when compared to other structural storm water practices, and they are ineffective at removing soluble pollutants (See Effectiveness).
- Dry extended detention ponds may become a nuisance due to mosquito breeding.
- Habitat destruction may occur during construction if the practice is designed in-stream or within the stream buffer.
- Although wet ponds can increase property values, dry ponds can actually detract from the value of a home (see Cost Considerations).

Dry extended detention ponds on their own only provide peak flow reduction and do little to control overall runoff volume, which could result in adverse downstream impacts.

Maintenance Considerations

In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed. Table 1 outlines some of these practices.

Effectiveness

Structural management practices can be used to achieve four broad resource protection goals: flood control, channel protection, ground water recharge, and pollutant removal. Dry extended detention basins can provide flood control and channel protection, as well as some pollutant removal.

Flood Control

One objective of storm water management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Dry extended detention basins can easily be designed for flood control, and this is actually the primary purpose of most extended detention ponds.

Table 1. Typical maintenance activities for dry ponds (Source: Modified from WMI, 1997)

Activity	Schedule
• Note erosion of pond banks or bottom	Semiannual inspection
• Inspect for damage to the embankment • Monitor for sediment accumulation in the facility and forebay • Examine to ensure that inlet and outlet devices are free of debris and operational	Annual inspection
• Repair undercut or eroded areas • Mow side slopes • Manage pesticide and nutrients • Remove litter and debris	Standard maintenance
• Seed or sod to restore dead or damaged ground cover	Annual maintenance (as needed)
• Remove sediment from the forebay	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pond volume has been reduced by 25 percent	25- to 50-year maintenance

Channel Protection

One result of urbanization is the geomorphic changes that occur in response to modified hydrology. Traditionally, dry extended detention basins have provided control of the 2-year storm (i.e., the storm that occurs, on average, once every 2 years) for channel protection. It appears that this control has been relatively ineffective, and recent research suggests that control of a smaller storm might be more appropriate (MacRae, 1996). Slightly modifying the design of dry extended detention basins to reduce the flow of smaller storm events might make them effective tools in reducing downstream erosion.

Pollutant Removal

Dry extended detention basins provide moderate pollutant removal, provided that the design features described in the Siting and Design Considerations section are incorporated. Although they can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants because of the absence of a permanent pool. A few studies are available on the effectiveness of dry extended detention ponds. Typical removal rates, as reported by Schueler (1997), are as follows:

Total suspended solids: 61%
Total phosphorus: 19%
Total nitrogen: 31%
Nitrate nitrogen: 9%
Metals: 26%–54%

There is considerable variability in the effectiveness of ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wet ponds. A recent joint project of the American Society of Civil Engineers (ASCE) and the USEPA Office of Water might help to isolate specific design features that can improve performance. The National Storm Water Best Management Practice (BMP) database is a compilation of storm water practices that includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. For more information on this database, access the ASCE web page at http://www.asce.org.

Cost Considerations

Dry extended detention ponds are the least expensive storm water management practice, on the basis of cost per unit area treated. The construction costs associated with these facilities range considerably. One recent study evaluated the cost of all pond systems (Brown and Schueler, 1997). Adjusting for inflation, the cost of dry extended detention ponds can be estimated with the equation

$$C = 12.4V^{0.760}$$

where:

C = Construction, design, and permitting cost, and

V = Volume needed to control the 10-year storm (ft^3).

Using this equation, typical construction costs are

$ 41,600 for a 1 acre-foot pond

$ 239,000 for a 10 acre-foot pond

$ 1,380,000 for a 100 acre-foot pond

Interestingly, these costs are generally slightly higher than the cost of wet ponds on a cost per total volume basis. Dry extended detention ponds are generally less expensive on a given site, however, because they are usually smaller than a wet pond design for the same site.

Ponds do not consume a large area compared to the total area treated (typically 2 to 3 percent of the contributing drainage area). It is important to note, however, that each pond is generally large. Other practices, such as filters or swales, may be "squeezed in" on relatively unusable land, but ponds need a relatively large continuous area.

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Finally, ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into pond systems can be spread over a relatively long time period.

Another economic concern associated with dry ponds is that they might detract slightly from the value of adjacent properties. One study found that dry ponds can actually detract from the perceived value of homes adjacent to a dry pond by between 3 and 10 percent (Emmerling-Dinovo, 1995).

References

Design References:

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Information Resources

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Wet Ponds

Postconstruction Storm Water Management in New Development and Redevelopment

Description

The primary functions of a wet pond are to detain storm water and facilitate pollutant removal through settling and biological uptake

Wet ponds (a.k.a. storm water ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season). Ponds treat incoming storm water runoff by settling and algal uptake. The primary removal mechanism is settling as storm water runoff resides in this pool, and pollutant uptake, particularly of nutrients, also occurs through biological activity in the pond. Wet ponds are among the most cost-effective and widely used storm water practices. While there are several different versions of the wet pond design, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain storm water runoff in order to provide settling.

Applicability

Wet ponds are widely applicable storm water management practices. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions.

Regional Applicability

Wet extended detention ponds can be applied in most regions of the United States, with the exception of arid climates. In arid regions, it is difficult to justify the supplemental water needed to maintain a permanent pool because of the scarcity of water. Even in semi-arid Austin, Texas, one study found that 2.6 acre-feet per year of supplemental water was needed to maintain a permanent pool of only 0.29 acre-feet (Saunders and Gilroy, 1997). Other modifications and design variations are needed in semi-arid and cold climates, and karst (i.e., limestone) topography.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in the ultra-urban environment because of the land area each pond consumes. They can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. A typical example is a gas station. Wet ponds can accept runoff from storm water hot spots, but need significant separation from ground water if they will be used for this purpose.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Wet ponds are very useful storm water retrofits and have two primary applications as a retrofit design. In many communities, detention ponds have been designed for flood control in the past. It is possible to modify these facilities to develop a permanent wet pool to provide water quality control (see Treatment under Design Considerations), and modify the outlet structure to provide channel protection. Alternatively, wet ponds may be designed in-stream, or in open areas as a part of a retrofit study.

Cold Water (Trout) Streams

Wet ponds pose a risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince George's County, Maryland, found that storm water wet ponds heat storm water by about 9°F from the inlet to the outlet (Galli, 1990).

Siting and Design Considerations

Siting Considerations

In addition to the restrictions and modifications to adapting wet ponds to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting wet ponds.

<u>Drainage Area</u>

Wet ponds need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall.

<u>Slope</u>

Wet ponds can be used on sites with an upstream slope up to about 15 percent. The local slope should be relatively shallow, however. Although there is no minimum slope requirement, there does need to be enough elevation drop from the pond inlet to the pond outlet to ensure that water can flow through the system.

<u>Soils / Topography</u>

Wet ponds can be used in almost all soils and geology, with minor design adjustments for regions of karst topography (see Design Considerations).

Ground Water

Unless they receive hot spot runoff, ponds can often intersect the ground water table. However, some research suggests that pollutant removal is reduced when ground water contributes substantially to the pool volume (Schueler, 1997b).

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wet pond designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10 percent of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Treatment

Treatment design features help enhance the ability of a storm water management practice to remove pollutants. The purpose of most of these features is to increase the amount of time that storm water remains in the pond.

One technique of increasing the pollutant removal of a pond is to increase the volume of the permanent pool. Typically, ponds are sized to be equal to the water quality volume (i.e., the volume of water treated for pollutant removal). Designers may consider using a larger volume to meet specific watershed objectives, such as phosphorous removal in a lake system. Regardless of the pool size, designers need to conduct a water balance analysis to ensure that sufficient inflow is available to maintain the permanent pool.

Other design features do not increase the volume of a pond, but can increase the amount of time storm water remains in the practice and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat storm water. Another feature that can improve treatment is to use multiple ponds in series as part of a "treatment train" approach to pollutant removal. This redundant treatment can also help slow the rate of flow through the system.

Conveyance

Storm water should be conveyed to and from all storm water management practices safely and to minimize erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. To help mitigate warming at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wet ponds is clogging of the outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3 inches in diameter. (Smaller orifices are more susceptible to clogging).

Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with a maintenance access to the forebay to ease this relatively routine (5–7 year) maintenance activity. In addition, ponds should generally have a pond drain to draw down the pond for the more infrequent dredging of the main cell of the pond.

Landscaping

Landscaping of wet ponds can make them an asset to a community and can also enhance the pollutant removal of the practice. A vegetated buffer should be preserved around the pond to protect the banks from erosion and provide some pollutant removal before runoff enters the pond by overland flow. In addition, ponds should incorporate an aquatic bench (i.e., a shallow shelf with wetland plants) around the edge of the pond. This feature may provide some pollutant uptake, and it also helps to stabilize the soil at the edge of the pond and enhance habitat and aesthetic value.

Design Variations

There are several variations of the wet pond design. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities.

Wet Extended Detention Pond

The wet extended detention pond combines the treatment concepts of the dry extended detention pond and the wet pond. In this design, the water quality volume is split between the permanent pool and detention storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 12 to 48 hours. This design has similar pollutant removal to a traditional wet pond and consumes less space. Wet extended detention ponds should be designed to maintain at least half the treatment volume of the permanent pool. In addition, designers need to carefully select vegetation to be planted in the extended detention zone to ensure that the selected vegetation can withstand both wet and dry periods.

Pocket Pond

In this design alternative, a pond drains a smaller area than a traditional wet pond, and the permanent pool is maintained by intercepting the ground water. While this design achieves less pollutant removal than a traditional wet pond, it may be an acceptable alternative on sites where space is at a premium, or in a retrofit situation.

Water Reuse Pond

Some designers have used wet ponds to act as a water source, usually for irrigation. In this case, the water balance should account for the water that will be taken from the pond. One study conducted in Florida estimated that a water reuse pond could provide irrigation for a 100-acre golf course at about one-seventh the cost of the market rate of the equivalent amount of water ($40,000 versus $300,000).

Regional Adaptations

Semi-Arid Climates

In arid climates, wet ponds are not a feasible option (see Applicability), but they may possibly be used in semi-arid climates if the permanent pool is maintained with a supplemental water source, or if the pool is allowed to vary seasonally. This choice needs to be seriously evaluated, however. Saunders and Gilroy (1997) reported that 2.6 acre-feet per year of supplemental water were needed to maintain a permanent pool of only 0.29 acre-feet in Austin, Texas.

Cold Climates

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load and a large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting, and sediment loads from road sanding, may impact pond vegetation as well as reduce the storage and treatment capacity of the pond.

One option to deal with high pollutant loads and runoff volumes during the spring snowmelt is the use of a seasonally operated pond to capture snowmelt during the winter, and retain the permanent pool during warmer seasons. In this option, proposed by Oberts (1994), the pond has two water quality outlets, both equipped with gate valves. In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring melt begins, the lower outlet is closed to provide detention for the melt event. This method can act as a substitute for using a minimum extended detention storage volume. When wetlands preservation is a downstream objective, seasonal manipulation of pond levels may not be desired. An analysis of the effects on downstream hydrology should be conducted before considering this option. In addition, the manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

Several other modifications may help to improve the performance of ponds in cold climates. Designers should consider planting the pond with salt-tolerant vegetation if the facility receives road runoff. In order to counteract the effects of freezing on inlet and outlet structures, the use of inlet and outlet structures that are resistant to frost, including weirs and larger diameter pipes, may be useful. Designing structures on-line, with a continuous flow of water through the pond, will also help prevent freezing of these structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it may be useful to incorporate extended detention into the design to retain usable treatment area above the permanent pool when it is frozen.

Karst Topography

In karst (i.e., limestone) topography, wet ponds should be designed with an impermeable liner to prevent ground water contamination or sinkhole formation, and to help maintain the permanent pool.

Limitations

Limitations of wet ponds include:

- If improperly located, wet pond construction may cause loss of wetlands or forest.
- Although wet ponds consume a small amount of space relative to their drainage areas, they are often inappropriate in dense urban areas because each pond is generally quite large.
- Their use is restricted in arid and semi-arid regions due to the need to supplement the permanent pool.
- In cold water streams, wet ponds are not a feasible option due to the potential for stream warming.
- Wet ponds may pose safety hazards.

Maintenance Considerations

In addition to incorporating features into the pond design to minimize maintenance, some regular maintenance and inspection practices are needed. The table below outlines these practices.

Table 1. Typical maintenance activities for wet ponds (Source: WMI, 1997)

Activity	Schedule
• If wetland components are included, inspect for invasive vegetation.	Semi-annual inspection
• Inspect for damage. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Monthly maintenance
• Manage and harvest wetland plants.	Annual maintenance (if needed)
• Remove sediment from the forebay.	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly or the pond becomes eutrophic.	20-to 50-year maintenance

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Wet ponds can provide flood control, channel protection, and pollutant removal.

Flood Control

One objective of storm water management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wet ponds can easily be designed for flood control by providing flood storage above the level of the permanent pool.

Channel Protection

When used for channel protection, wet ponds have traditionally controlled the 2-year storm. It appears that this control has been relatively ineffective, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996).

Ground Water Recharge

Wet ponds cannot provide ground water recharge. Infiltration is impeded by the accumulation of debris on the bottom of the pond.

Pollutant Removal

Wet ponds are among the most effective storm water management practices at removing storm water pollutants. A wide range of research is available to estimate the effectiveness of wet ponds. Table 2 summarizes some of the research completed on wet pond removal efficiency. Typical removal rates, as reported by Schueler (1997a) are:

Total Suspended Solids: 67%

Total Phosphorous: 48%

Total Nitrogen: 31%

Nitrate Nitrogen: 24%

Metals: 24–73%

Bacteria: 65%

Table 2. Wet pond percent removal efficiency data

Wet Pond Removal Efficiencies							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Practice Type**
City of Austin, TX 1991. Woodhollow, TX	54	46	39	45	69–76	46	wet pond
Driscoll 1983. Westleigh, MD	81	54	37	-	26–82	-	wet pond
Dorman et al., 1989. West Pond, MN	65	25	-	61	44–66	-	wet pond
Driscoll, 1983. Waverly Hills, MI	91	79	62	66	57–95	-	wet pond
Driscoll, 1983. Unqua, NY	60	45	-	-	80	86	wet pond
Cullum, 1985. Timber Creek, FL	64	60	15	80	-	-	wet pond
City of Austin, TX 1996. St. Elmo, TX.	92	80	19	-17	2–58	89-91	wet pond
Horner, Guedry, and Kortenhoff, 1990. SR 204, WA	99	91	-	-	88–90	-	wet pond
Horner, Guedry, and Kortenhoff, 1990. Seattle, WA	86.7	78.4	-	-	65–67	-	wet pond
Kantrowitz and Woodham, 1995. Saint Joe's Creek, FL	45	45	-	36	38–82	-	wet pond
Wu, 1989. Runaway Bay, NC	62	36	-	-	32–52	-	wet pond
Driscoll 1983. Pitt-AA, MI	32	18	-	7	13–62	-	wet pond
Bannerman and Dodds, 1992. Monroe Street, WI	90	65	-	-	65–75	70	wet pond
Horner, Guedry, and Kortenhoff, 1990. Mercer, WA	75	67	-	-	23–51	-	wet pond
Oberts, Wotzka, and Hartsoe 1989. McKnight, MN	85	48	30	24	67	-	wet pond
Yousef, Wanielista, and Harper 1986. Maitland, FL	-	-	-	87	77–96	-	wet pond
Wu, 1989. Lakeside Pond, NC	93	45	-	-	80–87	-	wet pond
Oberts, Wotzka, and Hartsoe, 1989. Lake Ridge, MN	90	61	41	10	73	-	wet pond

Table 2. (continued)

Wet Pond Removal Efficiencies							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Practice Type**
Driscoll, 1983. Lake Ellyn, IL	84	34	-	-	71-78	-	wet pond
Dorman et al., 1989. I-4, FL	54	69	-	97	47–74	-	wet pond
Martin, 1988. Highway Site, FL	83	37	30	28	50–77	-	wet pond
Driscoll, 1983. Grace Street, MI	32	12	6	-1	26	-	wet pond
Occoquan Watershed Monitoring Laboratory, 1983. Farm Pond, VA	85	86	34	-	-	-	wet pond
Occoquan Watershed Monitoring Laboratory, 1983. Burke, VA	-33.3	39	32	-	38–84	-	wet pond
Dorman et al., 1989. Buckland, CT	61	45	-	22	-25 to -51	-	wet pond
Holler, 1989. Boynton Beach Mall, FL	91	76	-	87	-	-	wet pond
Urbonas, Carlson, and Vang 1994. Shop Creek, CO	78	49	-12	-85	51–57	-	wet pond
Oberts and Wotzka, 1988. McCarrons, MN	91	78	85	-	90	-	wet pond
Gain, 1996. FL	54	30	16	24	42–73	-	wet pond
Ontario Ministry of the Environment, 1991. Uplands, Ontario	82	69	-	-	-	97	wet extended detention pond
Borden et al., 1996. Piedmont, NC	19.6	36.5	35.1	65.9	-4 to-97	-6	wet extended detention pond
Holler, 1990. Lake Tohopekaliga District, FL	-	85	-	-	-	-	wet extended detention pond
Ontario Ministry of the Environment 1991. Kennedy-Burnett, Ontario	98	79	54	-	21–39	99	wet extended detention pond
Ontario Ministry of the Environment 1991. East Barrhaven, Ontario	52	47	-	-	-	56	wet extended detention pond
Borden et al., 1996. Davis, NC	60.4	46.2	16	18.2	15–51	48	wet extended

							detention pond

There is considerable variability in the effectiveness of ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wet ponds. A recent joint project of the American Society of Civil Engineers (ASCE) and the USEPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of storm water practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. More information on this database is available from the ASCE web page at *www.asce.org*.

Cost Considerations

Wet ponds are relatively inexpensive storm water practices. The construction costs associated with these facilities range considerably. A recent study (Brown and Schueler, 1997) estimated the cost of a variety of storm water management practices. The study resulted in the following cost equation, adjusting for inflation:

$C = 24.5V^{0.705}$

where:

C = Construction, design and permitting cost;

V = Volume in the pond to include the 10-year storm (ft^3).

Using this equation, typical construction costs are:

$45,700 for a 1 acre-foot facility

$232,000 for a 10 acre-foot facility

$1,170,000 for a 100 acre-foot facility

Ponds do not consume a large area (typically 2–3 percent of the contributing drainage area). Therefore, the land consumed to design the pond will not be very large. It is important to note, however, that these facilities are generally large. Other practices, such as filters or swales, may be "squeezed" into relatively unusable land, but ponds need a relatively large continuous area.

For ponds, the annual cost of routine maintenance is typically estimated at about 3 to 5 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into pond systems may be spread over a relatively long time period.

In addition to the water resource protection benefits of wet ponds, there is some evidence to suggest that they may provide an economic benefit by increasing property values. The results of one study suggest that "pond front" property can increase the selling price of new properties by about 10 percent (USEPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25 percent when located near a wet pond (Emmerling-Dinovo, 1995).

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Infiltration practices

Infiltration Basin

Postconstruction Storm Water Management in New Development and Redevelopment

Description

An infiltration basin is a shallow impoundment which is designed to infiltrate storm water into the ground water. This practice is believed to have a high pollutant removal efficiency and can also help recharge the ground water, thus restoring low flows to stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

Infiltration basins are designed to collect storm water from impervious areas and provide pollutant removal benefits through detention and filtration

Applicability

Infiltration basins have select applications. Their use is often sharply restricted by concerns over ground water contamination, soils, and clogging at the site.

Regional Applicability

Infiltration basins can be utilized in most regions of the country, with some design modifications in cold and arid climates. In regions of karst (i.e., limestone) topography, these storm water management practices may not be applied due to concerns of sink hole formation and ground water contamination.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. In these areas, few storm water practices can be easily applied due to space limitations. Infiltration basins can rarely be applied in the ultra-urban environment. Two features that can restrict their use are the potential of infiltrated water to interfere with existing infrastructure, and the relatively poor infiltration capacity of most urban soils. In addition, while they consume only the space of the infiltration basin site itself, they need a continuous, relatively flat area. Thus, it is more difficult to fit them into small unusable areas on a site.

Storm Water Hot Spots

A storm water hot spot is an area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. Infiltration basins should never receive runoff from storm water hot spots, unless the storm water has already been treated by another practice. This caution is due to potential ground water contamination.

Storm Water Retrofit

A storm water retrofit is a storm water practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Infiltration basins have limited applications as a storm water retrofit. Their use is restricted by three factors. First, infiltration basins should be used to treat small sites (less than 5 acres). Practices that are applied to small sites, such as infiltration basins, are generally a high-cost retrofit option in terms of construction cost and the maintenance burden associated with the large number of practices needed to retrofit a watershed. Second, it is often difficult to find areas where soils are appropriate for infiltration in an already urban or suburban environment. Finally, infiltration basins are best applied to small sites, yet need a flat, relatively continuous area. It is often difficult to find sites with this type of area available.

Cold Water (Trout) Streams

Infiltration basins are an excellent option for cold water streams because they encourage infiltration of storm water and maintain dry weather flow. Because storm water travels underground to the stream, it has little opportunity to increase in temperature.

Siting and Design Considerations

When designing infiltration basins, designers need to carefully consider both the restrictions on the site and design features to improve the long-term performance of the practice.

Siting Considerations

Infiltration practices need to be located extremely carefully. In particular, designers need to ensure that the soils on the site are appropriate for infiltration, and that designs minimize the potential for ground water contamination and long-term maintenance problems.

<u>Drainage Area</u>

Infiltration basins have historically been used as regional facilities, serving for both quantity and quality control. In some regions of the country, this practice is feasible, particularly if the soils are particularly sandy. In most areas, however, infiltration basins experience high rates of failure when used in this manner. In general, the practice is best applied to relatively small drainage areas (i.e., less than 10 acres).

<u>Slope</u>

The bottom of infiltration basins needs to be completely flat to allow infiltration throughout the entire basin bottom.

<u>Soils/Topography</u>

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging, and soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for ground water contamination. The infiltration rate should range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20 percent clay content, and less than 40 percent silt/clay content (MDE, 2000). Finally, infiltration basins may not be used in regions of karst topography, due to the potential for sinkhole formation or ground water contamination.

Ground Water

Designers always need to provide significant separation distance (2 to 5 feet) from the bottom of the infiltration basin and the seasonally high ground water table, to reduce the risk of contamination. Infiltration practices should also be separated from drinking water wells.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration basin designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural management practices, but it is particularly important for infiltration practices. In order to ensure that pretreatment mechanisms are effective, designers should incorporate "multiple pretreatment," using practices such as grassed swales, sediment basins, and vegetated filter strips in series.

Treatment

Treatment design features enhance the pollutant removal of a practice. For infiltration practices, designers need to stabilize upland soils to ensure that the basin does not become clogged with sediment. In addition, the facility needs to be sized so that the volume of water to be treated infiltrates through the bottom in a given amount of time. Because infiltration basins are designed in this manner, infiltration basins designed on less permeable soils should be significantly larger than those designed on more permeable soils.

Conveyance

Storm water needs to be conveyed through storm water management practices safely and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. In general, infiltration basins should be designed to treat only small storms (i.e., only for water quality). Thus, these practices should be designed "off-line," using a flow separator to divert only small flows to the practice.

Maintenance Reduction

In addition to regular maintenance activities, designers also need to incorporate features into the design to ensure that the maintenance burden of a practice is reduced. These features can make regular maintenance activities easier or reduce the need to perform maintenance. In infiltration basins, designers need to provide access to the basin for regular maintenance activities. Where possible, a means to drain the basin, such as an underdrain, should be provided in case the bottom becomes clogged. This feature allows the basin to be drained and accessed for maintenance in the event that the water has ponded in the basin bottom or the soil is saturated.

Landscaping

Landscaping can enhance the aesthetic value of storm water practices or improve their function. In infiltration basins, the most important purpose of vegetation is to reduce the tendency of the practice to clog. Upland drainage needs to be properly stabilized with a thick layer of vegetation, particularly immediately following construction. In addition, providing a thick turf at the basin bottom helps encourage infiltration and prevent the formation of rills in the basin bottom.

Design Variations

Some modifications may be needed to ensure the performance of infiltration basins in arid and cold climates.

Arid or Semi-Arid Climates

In arid regions, infiltration practices are often highly recommended because of the need to recharge the ground water. In arid regions, designers need to emphasize pretreatment even more strongly to ensure that the practice does not clog, because of the high sediment concentrations associated with storm water runoff in areas such as the Southwest. In addition, the basin bottom may be planted with drought-tolerant species and/or covered with an alternative material such as sand or gravel.

Cold Climates

In extremely cold climates (i.e., regions that experience permafrost), infiltration basins may be an infeasible option. In most cold climates, infiltration basins can be a feasible practice, but there are some challenges to its use. First, the practice may become inoperable during some portions of the year when the surface of the basin becomes frozen. Other design features also may be incorporated to deal with the challenges of cold climates. One such challenge is the volume of runoff associated with the spring snowmelt event. The capacity of the infiltration basin might be increased to account for snowmelt volume.

Another option is the use of a seasonably operated facility (Oberts, 1994). A seasonally operated infiltration/detention basin combines several techniques to improve the performance of infiltration practices in cold climates. Two features, the underdrain system and level control valves, are useful in cold climates. These features are used as follows: At the beginning of the winter season, the level control valve is opened and the soil is drained. As the snow begins to melt in the spring, the underdrain and the level control valves are closed. The snowmelt is infiltrated until the capacity of the soil is reached. Then, the facility acts as a detention facility, providing storage for particles to settle.

Other design features can help to minimize problems associated with winter conditions, particularly concerns that chlorides from road salting may contaminate ground water. The basin may be disconnected during the winter to ensure that chlorides do not enter the ground water in areas where this is a problem, or if the basin is used to treat roadside runoff. Designers may also want to reconsider application of infiltration practices on parking lots or roads where deicing is used, unless it is confirmed that the practice will not cause elevated chloride levels in the ground water. If the basin is used for snow storage, or to treat roadside or parking lot runoff, the basin bottom should be planted with salt-tolerant vegetation.

Limitations

Although infiltration basins can be useful practices, they have several limitations. Infiltration basins are not generally aesthetic practices, particularly if they clog. If they clog, the soils become saturated, and the practice can be a source of mosquitoes. In addition, these practices are challenging to apply because of concerns over ground water contamination and sufficient soil infiltration. Finally, maintenance of infiltration practices can be burdensome, and they have a relatively high rate of failure.

Maintenance Considerations

Regular maintenance is critical to the successful operation of infiltration basins (see Table 1). Historically, infiltration basins have had a poor track record. In one study conducted in Prince George's County, Maryland (Galli, 1992), all of the infiltration basins investigated clogged within 2 years. This trend may not be the same in soils with high infiltration rates, however. A study of 23 infiltration basins in the Pacific Northwest showed better long-term performance in an area with highly permeable soils (Hilding, 1996). In this study, few of the infiltration basins had failed after 10 years.

Table 1. Typical maintenance activities for infiltration basins (Source: Modified from WMI, 1997)

Activity	Schedule
• Inspect facility for signs of wetness or damage to structures • Note eroded areas. • If dead or dying grass on the bottom is observed, check to ensure that water percolates 2–3 days following storms. • Note signs of petroleum hydrocarbon contamination and handle properly.	Semi-annual inspection
• Mow and remove litter and debris. • Stabilize of eroded banks. • Repair undercut and eroded areas at inflow and outflow structures.	Standard maintenance (as needed)
• Disc or otherwise aerate bottom. • Dethatch basin bottom.	Annual maintenance
• Scrape bottom and remove sediment. Restore original cross-section and infiltration rate. • Seed or sod to restore ground cover.	5-year maintenance

Effectiveness

Structural management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Infiltration basins can provide ground water recharge and pollutant removal.

Ground Water Recharge

Infiltration basins recharge the ground water because runoff is treated for water quality by filtering through the soil and discharging to ground water.

Pollutant Removal

Very little data are available regarding the pollutant removal associated with infiltration basins. It is generally assumed that they have very high pollutant removal because none of the storm water entering the practice remains on the surface. Schueler (1987) estimated pollutant removal for infiltration basins based on data from land disposal of wastewater. The average pollutant removal, assuming the infiltration basin is sized to treat the runoff from a 1-inch storm, is:

TSS 75%

Phosphorous 60–70%

Nitrogen 55–60%

Metals 85–90%

Bacteria 90%

These removal efficiencies assume that the infiltration basin is well designed and maintained. The information in the Siting and Design Considerations and Maintenance Considerations sections represent the best available information on how to properly design these practices. The design references below also provide additional information.

Cost Considerations

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about \$2 per ft^3 (adjusted for inflation) of storage for a 0.25-acre basin (SWRPC, 1991). Infiltration basins typically consume about 2 to 3 percent of the site draining to them, which is relatively small. Maintenance costs are estimated at 5 to 10 percent of construction costs.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration basins have a high failure rate (see Maintenance Considerations). Thus, it may be necessary to replace the basin after a relatively short period of time.

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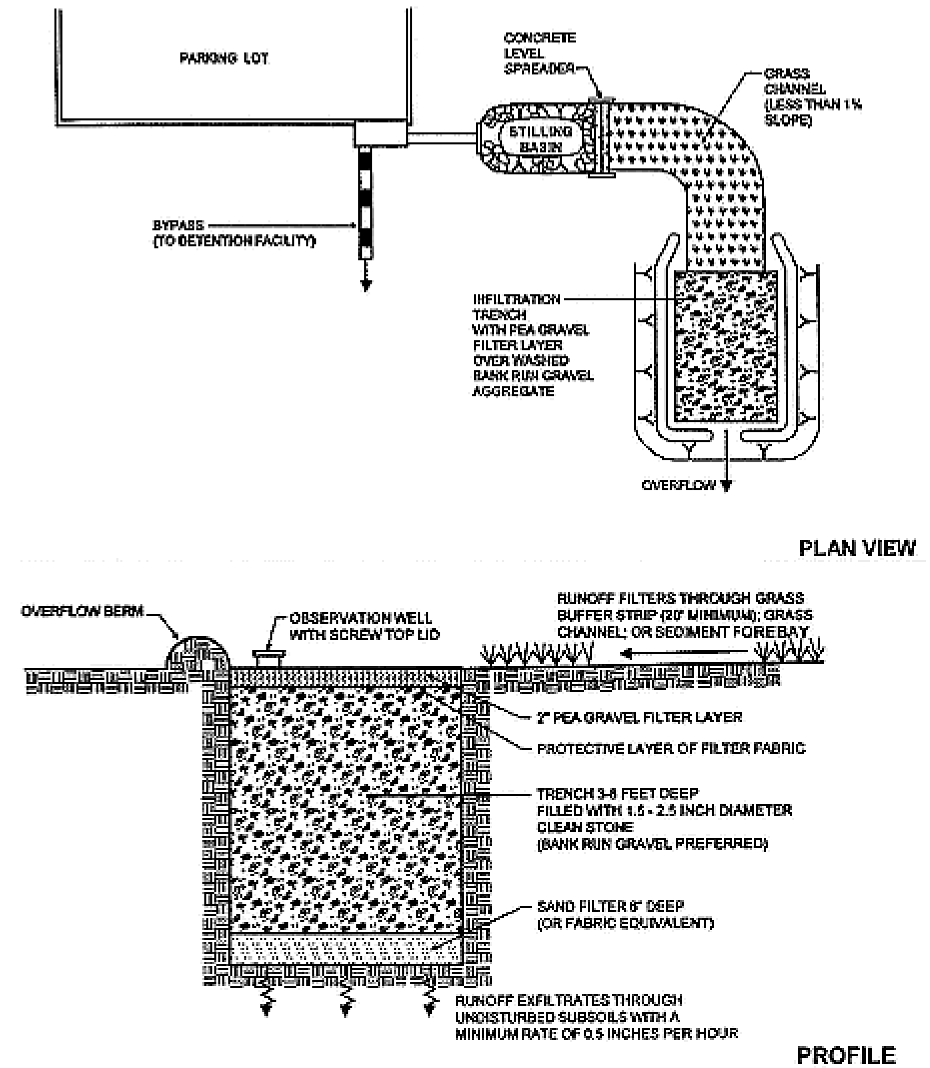
Infiltration Trench

Postconstruction Storm Water Management in New Development and Redevelopment

Description

An infiltration trench (a.k.a. infiltration galley) is a rock-filled trench with no outlet that receives storm water runoff. Storm water runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is filtering through the soil.



A schematic of an infiltration trench (Source: MDE, 2000)

Applicability

Infiltration trenches have select applications. While they can be applied in most regions of the country, their use is sharply restricted by concerns due to common site factors, such as potential ground water contamination, soils, and clogging.

Regional Applicability

Infiltration trenches can be utilized in most regions of the country, with some design modifications in cold and arid climates. In regions of karst (i.e., limestone) topography, these storm water management practices may not be applied due to concerns of sink hole formation and ground water contamination.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Infiltration trenches can sometimes be applied in the ultra-urban environment. Two features that can restrict their use are the potential of infiltrated water to interfere with existing infrastructure, and the relatively poor infiltration of most urban soils.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. Infiltration trenches should not receive runoff from storm water hot spots, unless the storm water has already been treated by another storm water management practice, because of potential ground water contamination.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Infiltration trenches may be used as a storm water retrofit. Their use is somewhat restricted, however, by two factors. First, infiltration trenches should be used to treat small sites (less than 5 acres). Small site storm water management practices are generally a high cost retrofit option in terms of construction cost and the maintenance burden associated with the number of small site practices. Second, it is often difficult to find areas where soils are appropriate for infiltration in an already urban or suburban environment.

Cold Water (Trout) Streams

Infiltration trenches are an excellent option for cold water streams because they encourage infiltration of storm water. This storm water does not warm as it travels underground to the receiving stream, lessening the temperature impacts commonly associated with urbanization.

Siting and Design Considerations

Infiltration trenches have select applications. Although they can be applied in a variety of situations, the use of infiltration trenches is restricted by concerns over ground water contamination, soils, and clogging.

Siting Considerations

Infiltration practices need to be sited extremely carefully. In particular, designers need to ensure that the soils on site are appropriate for infiltration and that designs minimize the potential for ground water contamination and long-term maintenance.

Drainage Area

Infiltration trenches generally can be applied to relatively small sites (less than 5 acres), with relatively high impervious cover. Application to larger sites generally causes clogging, resulting in a high maintenance burden.

Slope

Infiltration trenches should be placed on flat ground, but the slopes of the site draining to the practice can be as steep as 15 percent.

Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the storm water can infiltrate quickly enough to reduce the potential for clogging. In addition, soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for ground water contamination. The infiltration rate should range between 0.5 and 3 inches per hour. In addition, the soils should have no greater than 20-percent clay content, and less than 40-percent silt/clay content (MDE, 2000). The infiltration rate and textural class of the soil need to be confirmed in the field; designers should not rely on more generic information such as a soil survey. Finally, infiltration trenches may not be used in regions of karst topography, due to the potential for sinkhole formation or ground water contamination.

Ground Water

Designers always need to provide significant separation (2 to 5 feet) from the bottom of the infiltration trench and the seasonally high ground water table, to reduce the risk of contamination. In addition, infiltration practices should be separated from drinking water wells.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration trench designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural storm water management practices, but it is particularly important for infiltration practices. To ensure that pretreatment mechanisms are effective, designers should incorporate "multiple pretreatment," using practices such as grassed swales, vegetated filter strips, detention, or a plunge pool in series.

Treatment

Treatment design features enhance the pollutant removal of a practice. During the construction process, the upland soils of infiltration trenches need to be stabilized to ensure that the trench does not become clogged with sediment. Furthermore, the practice should be filled with large clean stones that can retain the volume of water to be treated in their voids. Like infiltration basins, this practice should be sized so that the volume to be treated can infiltrate out of the trench bottom in 24 hours.

Conveyance

Storm water needs to be conveyed through storm water management practices safely, and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. Infiltration trenches should be designed to treat only small storms, (i.e., only for water quality). Thus, these practices should be designed "off-line," using a structure to divert only small flows to the practice. Finally, the sides of an infiltration trench should be lined with a geotextile fabric to prevent flow from causing rills along the edge of the practice.

Maintenance Reduction

In addition to regular maintenance activities, designers also need to incorporate features into the design to ensure that the maintenance burden of a practice is reduced. These features can make regular maintenance activities easier or reduce the need to perform maintenance. As with all management practices, infiltration trenches should have an access path for maintenance activities. An observation well (i.e., a perforated PVC pipe that leads to the bottom of the trench) can enable inspectors to monitor the drawdown rate. Where possible, trenches should have a means to drain the practice if it becomes clogged, such as an underdrain. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of filtering practices to collect and remove filtered runoff. An underdrain pipe with a shutoff valve can be used in an infiltration system to act as an overflow in case of clogging.

Landscaping

In infiltration trenches, there is no landscaping on the practice itself, but it is important to ensure that the upland drainage is properly stabilized with thick vegetation, particularly following construction.

Regional Variations

Arid or Semi-Arid Climates

In arid regions, infiltration practices are often highly recommended because of the need to recharge the ground water. One concern in these regions is the potential of these practices to clog, due to relatively high sediment concentrations in these environments. Pretreatment needs to be more heavily emphasized in these dryer climates.

Cold Climates

In extremely cold climates (i.e., regions that experience permafrost), infiltration trenches may be an infeasible option. In most cold climates, infiltration trenches can be a feasible management practice, but there are some challenges to their use. The volume may need to be increased in order to treat snowmelt. In addition, if the practice is used to treat roadside runoff, it may be desirable to divert flow around the trench in the winter to prevent infiltration of chlorides from road salting, where this is a problem. Finally, a minimum setback from roads is needed to ensure that the practice does not cause frost heaving.

Limitations

Although infiltration trenches can be a useful management practice, they have several limitations. While they do not detract visually from a site, infiltration trenches provide no visual enhancements. Their application is limited due to concerns over ground water contamination and other soils requirements. Finally, maintenance can be burdensome, and infiltration practices have a relatively high rate of failure.

Maintenance Considerations

In addition to incorporating features into the design to minimize maintenance, some regular maintenance and inspection practices are needed. Table 1 outlines some of these practices.

Table 1. Typical maintenance activities for infiltration trenches (Source: Modified from WMI, 1997)

Activity	Schedule
• Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.	Semi-annual inspection
• Remove sediment and oil/grease from pretreatment devices and overflow structures.	Standard maintenance
• If bypass capability is available, it may be possible to regain the infiltration rate in the short term by using measures such as providing an extended dry period.	5-year maintenance
• Total rehabilitation of the trench should be conducted to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate limit. • Trench walls should be excavated to expose clean soil.	Upon failure

Infiltration practices have historically had a high rate of failure compared to other storm water management practices. One study conducted in Prince George's County, Maryland (Galli, 1992), revealed that less than half of the infiltration trenches investigated (of about 50) were still functioning properly, and less than one-third still functioned properly after 5 years. Many of these practices, however, did not incorporate advanced pretreatment. By carefully selecting the location and improving the design features of infiltration practices, their performance should improve.

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Infiltration trenches can provide ground water recharge, pollutant control, and can help somewhat to provide channel protection.

Ground Water Recharge

Infiltration trenches recharge the ground water because runoff is treated for water quality by filtering through the soil and discharging to ground water.

Pollutant Removal

Very little data are available regarding the pollutant removal associated with infiltration trenches. It is generally assumed that they have very high pollutant removal, because none of the storm water entering the practice remains on the surface. Schueler (1987) estimated pollutant removal for infiltration trenches based on data from land disposal of wastewater. The average pollutant removal, assuming the infiltration trench is sized to treat the runoff from a 1-inch storm, is:

TSS 75%

Phosphorous 60–70%

Nitrogen 55–60%

Metals 85–90%

Bacteria 90%

These removal efficiencies assume that the infiltration trench is well designed and maintained. The information in the Siting and Design Considerations and Maintenance Considerations sections represent the best available information on how to properly design these practices. The design references below provide additional information.

Cost Considerations

Infiltration trenches are somewhat expensive, when compared to other storm water practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about \$5 per ft^3 of storm water treated (SWRPC, 1991; Brown and Schueler, 1997).

Infiltration trenches typically consume about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration trenches have a high failure rate (see Maintenance Considerations). In general, maintenance costs for infiltration trenches are estimated at between

5 percent and 20 percent of the construction cost. More realistic values are probably closer to the 20-percent range, to ensure long-term functionality of the practice.

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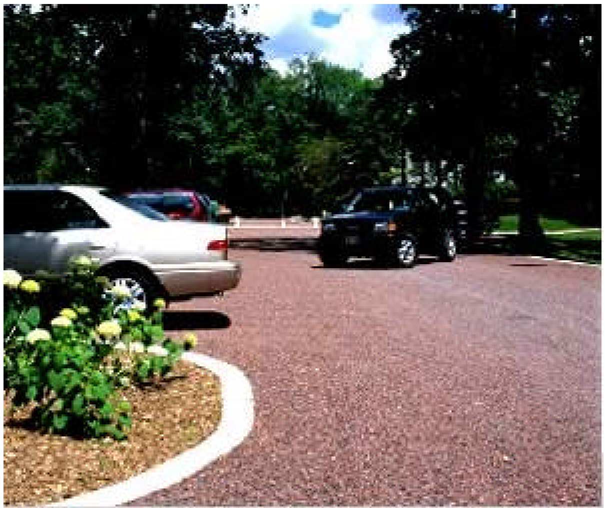
Porous Pavement

Postconstruction Storm Water Management in New Development and Redevelopment

Description



A porous pavement parking lot (Source: Invisible Structures, no date)

Porous pavement is a permeable pavement surface with an underlying stone reservoir to temporarily store surface runoff before it infiltrates into the subsoil. This porous surface replaces traditional pavement, allowing parking lot storm water to infiltrate directly and receive water quality treatment. There are a few porous pavement options, including porous asphalt, pervious concrete, and grass pavers. Porous asphalt and pervious concrete appear to be the same as traditional pavement from the surface, but are manufactured without "fine" materials, and incorporate void spaces to allow infiltration. Grass pavers are concrete interlocking blocks or synthetic fibrous gridded systems with open areas designed to allow grass to grow within the void areas. Other alternative paving surfaces can help reduce the runoff from paved areas but do not incorporate the stone trench for temporary storage below the pavement (see Green Parking fact sheet). While porous pavement has the potential to be a highly effective treatment practice, maintenance has been a concern in past applications of the practice.

Application

The ideal application for porous pavement is to treat low-traffic or overflow parking areas. Porous pavement may also have some application on highways, where it is currently used as a surface material to reduce hydroplaning.

Regional Applicability

Porous pavement can be applied in most regions of the country, but the practice has unique challenges in cold climates. Porous pavement cannot be used where sand is applied to the pavement surface because the sand will clog the surface of the material. Care also needs to be taken when applying salt to a porous pavement surface as chlorides from road salt may migrate into the ground water. For block pavers, plowing may be challenging because the edge of the snow plow blade can catch the edge of the blocks, damaging the surface. This difficulty does not imply that it is impossible to use porous pavement in cold climates. Another concern in cold climates is that infiltrating runoff below pavement may cause frost heave, although design modifications can reduce this risk. Porous pavement has been used successfully in Norway (Stenmark, 1995), incorporating design features to reduce frost heave. Furthermore, some experience suggests that snow melts faster on a porous surface because of rapid drainage below the snow surface (Cahill Associates, 1993).

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Porous pavements are a good option in these areas because they consume no space. They are not ideal for high-traffic areas, however, because of the potential for failure due to clogging (Galli, 1992).

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. These areas include commercial nurseries, auto recycle facilities, commercial parking lots, fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/unloading facilities, public works storage areas, hazardous materials generators (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing/steam cleaning facilities. Since porous pavement is an infiltration practice, it should not be applied on storm water hot spots due to the potential for ground water contamination.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Since porous pavement can only be applied to relatively small sites, using porous pavement as a primary tool for watershed retrofitting would be expensive. The best application of porous pavement for retrofits is on individual sites where a parking lot is being resurfaced.

Cold Water (Trout) Streams

Porous pavement can help to reduce the increased temperature commonly associated with increased impervious cover. Storm water ponds on the surface of conventional pavement, and is subsequently heated by the sun and hot pavement surface. By rapidly infiltrating rainfall, porous pavement reduces the time that storm water is exposed to the sun and heat.

Siting and Design Considerations

Siting Considerations

Porous pavement has the same siting considerations as other infiltration practices (see Infiltration Trench fact sheet). The site needs to meet the following criteria:

- Soils need to have a permeability between 0.5 and 3.0 inches per hour.
- The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface.
- Porous pavement should be sited at least 2 to 5 feet above the seasonally high ground water table, and at least 100 feet away from drinking water wells.
- Porous pavement should be sited on low-traffic or overflow parking areas, which are not sanded for snow removal.

Design Considerations

Some basic features should be incorporated into all porous pavement practices. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

1. *Pretreatment*. In porous pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Because the surface serves this purpose, frequent maintenance of the surface is critical to prevent clogging. Another pretreatment item can be the incorporation of a fine gravel layer above the coarse gravel treatment reservoir. Both of these pretreatment measures are marginal, which is one reason that these systems have a high failure rate.

2. *Treatment*. The stone reservoir below the pavement surface should be composed of layers of small stone directly below the pavement surface, and the stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, porous pavement is sized to treat a small event, such as a water quality storm (i.e., the storm that will be treated for pollutant removal), which can range from 0.5 to 1.5 inches. As in infiltration trenches, water can be stored only in the void spaces of the stone reservoir.

Conveyance. Water is conveyed to the stone reservoir through the surface of the pavement and infiltrates into the ground through the bottom of this stone reservoir. A geosynthetic liner and sand layer should be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs also need some method to convey larger storms to the storm drain system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would bypass flows that are too large to be treated by the system or when the surface clogs.

3. *Maintenance Reduction*. One nonstructural component that can help ensure proper maintenance of porous pavement is the use of a carefully worded maintenance agreement that provides specific guidance, including how to conduct routine maintenance and how the surface should be repaved. Ideally, signs should be posted on the site identifying porous pavement areas.

   One design option incorporates an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the surface of the pavement. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, storm water will flow over the surface and into the trench, where some infiltration and treatment will occur.

4. *Landscaping*. For porous pavement, the most important landscaping feature is a fully stabilized upland drainage. Reducing sediment loads entering the pavement can help to prevent clogging.

Design Variations

In one design variation, the stone reservoir below the filter can also treat runoff from other sources such as rooftop runoff. In this design, pipes are connected to the stone reservoir to direct flow throughout the bottom of the storage reservoir (Cahill Associates, 1993; Schueler, 1987). If used to treat off-site runoff, porous pavement should incorporate pretreatment, as with all structural management practices.

Regional Adaptations

In cold climates, the base of the stone reservoir should be below the frost line. This modification will help to reduce the risk of frost heave.

Limitations

In addition to the relatively strict siting requirements of porous pavement, a major limitation to the practice is the poor success rate it has experienced in the field. Several studies indicate that, with proper maintenance, porous pavement can retain its permeability (e.g., Goforth et al., 1983; Gburek and Urban, 1980; Hossain and Scofield, 1991). When porous pavement has been implemented in communities, however, the failure rate has been as high as 75 percent over 2 years (Galli, 1992).

Maintenance Considerations

Porous pavement requires extensive maintenance compared with other practices. In addition to owners not being aware of porous pavement on a site, not performing these maintenance activities is the chief reason for failure of this practice. Typical requirements are shown in Table 1.

Table 1. Typical maintenance activities for porous pavement (Source: WMI, 1997)

Activity	Schedule
• Avoid sealing or repaving with non-porous materials.	N/A
• Ensure that paving area is clean of debris. • Ensure that paving dewaters between storms. • Ensure that the area is clean of sediments.	Monthly
• Mow upland and adjacent areas, and seed bare areas. • Vacuum sweep frequently to keep the surface free of sediment.	As needed (typically three to four times per year).
• Inspect the surface for deterioration or spalling.	Annual

Effectiveness

Porous pavement can be used to provide ground water recharge and to reduce pollutants in storm water runoff. Some data suggest that as much as 70 to 80 percent of annual rainfall will go toward ground water recharge (Gburek and Urban, 1980). These data will vary depending on design characteristics and underlying soils. Two studies have been conducted on the long-term pollutant removal of porous pavement, both in the Washington, DC, area. They suggest high pollutant removal, although it is difficult to extrapolate these results to all applications of the practice. The results of the studies are presented in Table 2.

Table 2. Effectiveness of porous pavement pollutant removal (Schueler, 1987)

	Pollutant Removal (%)				
Study	**TSS**	**TP**	**TN**	**COD**	**Metals**
Prince William, VA	82	65	80	-	-
Rockville, MD	95	65	85	82	98–99

Cost Considerations

Porous pavement is significantly more expensive than traditional asphalt. While traditional asphalt is approximately \$0.50 to \$1.00 per ft^2, porous pavement can range from \$2 to \$3 per ft^2, depending on the design (CWP, 1998; Schueler, 1987). Subtracting the cost of traditional pavement, this amounts to approximately \$45,000 and \$100,000 per impervious acre treated, which would be quite expensive. In addition, the cost of vacuum sweeping may be substantial if a community does not already perform vacuum sweeping operations. Finally, the practice life may be very short because the risk of clogging is high.

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Filtration practices

Bioretention

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Bioretention areas are landscaping features adapted to provide on-site treatment of storm water runoff. They are commonly located in parking lot islands or within small pockets of residential land uses. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. During storms, runoff ponds above the mulch and soil in the system. Runoff from larger storms is generally diverted past the facility to the storm drain system. The remaining runoff filters through the mulch and prepared soil mix. Typically, the filtered runoff is collected in a perforated underdrain and returned to the storm drain system.

Bioretention areas can be used in parking areas to collect and treat storm water (Source: University of Maryland, 2000)

Applicability

Bioretention systems are generally applied to small sites and in a highly urbanized setting. Bioretention can be applied in many climatological and geologic situations, with some minor design modifications.

Regional Applicability

Bioretention systems are applicable almost everywhere in the United States. In arid or cold climates, however, some minor design modifications may be needed.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Bioretention facilities are ideally suited to many ultra-urban areas, such as parking lots. While they consume a fairly large amount of space (approximately 5 percent of the area that drains to them), they can be fit into existing parking lot islands or other landscaped areas.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. A typical example is a gas station or convenience store parking lot. Bioretention areas can be used to treat storm water hot spots as long as an impermeable liner is used at the bottom of the filter bed.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Bioretention can be used as a storm water retrofit, by modifying existing landscaped areas, or if a parking lot is being resurfaced. In highly urbanized areas, this is one of the few retrofit options that can be employed. However, it is very expensive to retrofit an entire watershed or subwatershed using storm water management practices designed to treat small sites.

Cold Water (Trout) Streams

Some species in cold water streams, notably trout, are extremely sensitive to changes in temperature. In order to protect these resources, designers should avoid treatment practices that increase the temperature of the storm water runoff they treat. Bioretention is a good option in cold water streams because water ponds in them for only a short time, decreasing the potential for stream warming.

Siting and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Siting

Some considerations for selecting a storm water management practice are the drainage area the practice will need to treat, the slopes both at the location of the practice and the drainage area, soil and subsurface conditions, and the depth of the seasonably high ground water table. Bioretention can be applied on many sites, with its primary restriction being the need to apply the practice on small sites.

<u>Drainage Area</u>

Bioretention areas should usually be used on small sites (i.e., 5 acres or less). When used to treat larger areas, they tend to clog. In addition, it is difficult to convey flow from a large area to a bioretention area.

<u>Slope</u>

Bioretention areas are best applied to relatively shallow slopes (usually about 5 percent). However, sufficient slope is needed at the site to ensure that water that enters the bioretention area can be connected with the storm drain system. These storm water management practices are most often applied to parking lots or residential landscaped areas, which generally have shallow slopes.

Soils/Topography

Bioretention areas can be applied in almost any soils or topography, since runoff percolates through a man-made soil bed and is returned to the storm water system.

Ground Water

Bioretention should be separated somewhat from the ground water to ensure that the ground water table never intersects with the bed of the bioretention facility. This design consideration prevents possible ground water contamination.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most bioretention area designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment refers to features of a management practice that cause coarse sediment particles and their associated pollutants to settle. Incorporating pretreatment helps to reduce the maintenance burden of bioretention and reduces the likelihood that the soil bed will clog over time. Several different mechanisms can be used to provide pretreatment in bioretention facilities. Often, runoff is directed to a grass channel or filter strip to filter out coarse materials before the runoff flows into the filter bed of the bioretention area. Other features may include a pea gravel diaphragm, which acts to spread flow evenly and drop out larger particles.

Treatment

Treatment design features help enhance the ability of a storm water management practice to remove pollutants. Several basic features should be incorporated into bioretention designs to enhance their pollutant removal. The bioretention system should be sized between 5 and 10 percent of the impervious area draining to it. The practice should be designed with a soil bed that is a sand/soil matrix, with a mulch layer above the soil bed. The bioretention area should be designed to pond a small amount of water (6–9 inches) above the filter bed.

Conveyance

Conveyance of storm water runoff into and through a storm water practice is a critical component of any storm water management practice. Storm water should be conveyed to and from practices safely and to minimize erosion potential. Ideally, some storm water treatment can be achieved during conveyance to and from the practice.

Bioretention practices are designed with an underdrain system to collect filtered runoff at the bottom of the filter bed and direct it to the storm drain system. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of the filter bed. Designers should provide an overflow structure to convey flow from storms that are not treated by the bioretention facility to the storm drain.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to reduce the required maintenance of a practice. Designers should ensure that the bioretention area is easily accessible for maintenance.

Landscaping

Landscaping is critical to the function and aesthetic value of bioretention areas. It is preferable to plant the area with native vegetation, or plants that provide habitat value, where possible. Another important design feature is to select species that can withstand the hydrologic regime they will experience. At the bottom of the bioretention facility, plants that tolerate both wet and dry conditions are preferable. At the edges, which will remain primarily dry, upland species will be the most resilient. Finally, it is best to select a combination of trees, shrubs, and herbaceous materials.

Design Variations

One design alternative to the traditional bioretention practice is the use of a "partial exfiltration" system, used to promote ground water recharge. Other design modifications may make this practice more effective in arid or cold climates.

Partial Exfiltration

In one design variation of the bioretention system, the underdrain is only installed on part of the bottom of the bioretention system. This design alternative allows for some infiltration, with the underdrain acting as more of an overflow. This system can be applied only when the soils and other characteristics are appropriate for infiltration (see Infiltration Trench and Infiltration Basin).

Arid Climates

In arid climates, bioretention areas should be landscaped with drought-tolerant species.

Cold Climates

In cold climates, bioretention areas can be used as snow storage areas. If used for this purpose, or if used to treat runoff from a parking lot where salt is used as a deicer, the bioretention area should be planted with salt-tolerant, nonwoody plant species.

Limitations

Bioretention areas have a few limitations. Bioretention areas cannot be used to treat a large drainage area, limiting their usefulness for some sites. In addition, although the practice does not consume a large amount of space, incorporating bioretention into a parking lot design may reduce the number of parking spaces available. Finally, the construction cost of bioretention areas is relatively high compared with many other management practices (see Cost Considerations).

Maintenance Considerations

Bioretention requires frequent landscaping maintenance, including measures to ensure that the area is functioning properly, as well as maintenance of the landscaping on the practice. In many cases, bioretention areas initially require intense maintenance, but less maintenance is needed over time. In many cases, maintenance tasks can be completed by a landscaping contractor, who may already be hired at the site.

Table 1. Typical maintenance activities for bioretention areas (Source: ETA and Biohabitats, 1993)

Activity	Schedule
• Remulch void areas • Treat diseased trees and shrubs • Mow turf areas	As needed
• Water plants daily for 2 weeks	At project completion
• Inspect soil and repair eroded areas • Remove litter and debris	Monthly
• Remove and replace dead and diseased vegetation	Twice per year
• Add mulch • Replace tree stakes and wires	Once per year

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. In general, bioretention areas can provide only pollutant removal.

Flood Control

Bioretention areas are not designed to provide flood control. These larger flows must be diverted to a detention pond that can provide flood peak reduction.

Channel Protection

Bioretention areas are generally not designed to provide channel protection because at the scale at which they are typically installed they are not able to infiltrate large volumes. (They are typically designed to treat and infiltrate the first inch of runoff and are bypassed by larger flows that can erode channels.) Channel protection must be provided by other means, such as ponds or other volume control practices.

Ground Water Recharge

Bioretention areas do not usually recharge the ground water, except in the case of the partial exfiltration design (see Design Variations).

Pollutant Removal

Little pollutant removal data have been collected on the pollutant removal effectiveness of bioretention areas. A field and laboratory analysis of bioretention facilities conducted by Davis et al. (1997), showed very high removal rates (roughly 95 percent for copper, 98 percent for phosphorus, 20 percent for nitrate, and 50 percent for total Kjeldhal nitrogen (TKN). Table 2 shows data from two other studies of field bioretention sites in Maryland.

Table 2. Pollutant removal effectiveness of two bioretention areas in Maryland (USEPA, 2000).

Pollutant	Pollutant Removal
Copper	43%–97%
Lead	70%–95%
Zinc	64%–95%
Phosphorus	65%–87%
TKN	52–67%
NH_4^+	92%
NO_3^-	15%–16%
Total nitrogen (TN)	49%
Calcium	27%

Assuming that bioretention systems behave similarly to swales, their removal rates are relatively high. The negative removal rate for bacteria may reflect sampling errors, such as failure to account for bacterial sources in the practice. Alternatively, these data may be the result of bacteria reproduction in the moist soils of swale systems.

There is considerable variability in the effectiveness of bioretention areas, and it is believed that properly designing and maintaining these areas may help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of bioretention areas. A recent joint project of the American Society of Civil Engineers (ASCE) and the EPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of storm water practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal might be made. More information on this database is accessible on the ASCE web page at http://www.asce.org.

Cost Considerations

Bioretention areas are relatively expensive. A recent study (Brown and Schueler, 1997) estimated the cost of a variety of storm water management practices. The study resulted in the following cost equation for bioretention areas, adjusting for inflation:

$C = 7.30\ V^{0.99}$

where:

C = Construction, design, and permitting cost ($); and

V = Volume of water treated by the facility (ft^3).

An important consideration when evaluating the costs of bioretention is that this practice replaces an area that most likely would have been landscaped. Thus, the true cost of the practice is less than the construction cost reported. Similarly, maintenance activities conducted on bioretention areas are not very different from maintenance of a landscaped area. The land consumed by bioretention areas is relatively high compared with other practices (about 5 percent of the drainage area). Again, this area should not necessarily be considered lost, since the practice may only be slightly larger than a traditional landscaped area. Finally, bioretention areas can improve upon existing landscaping and can therefore be an aesthetic benefit.

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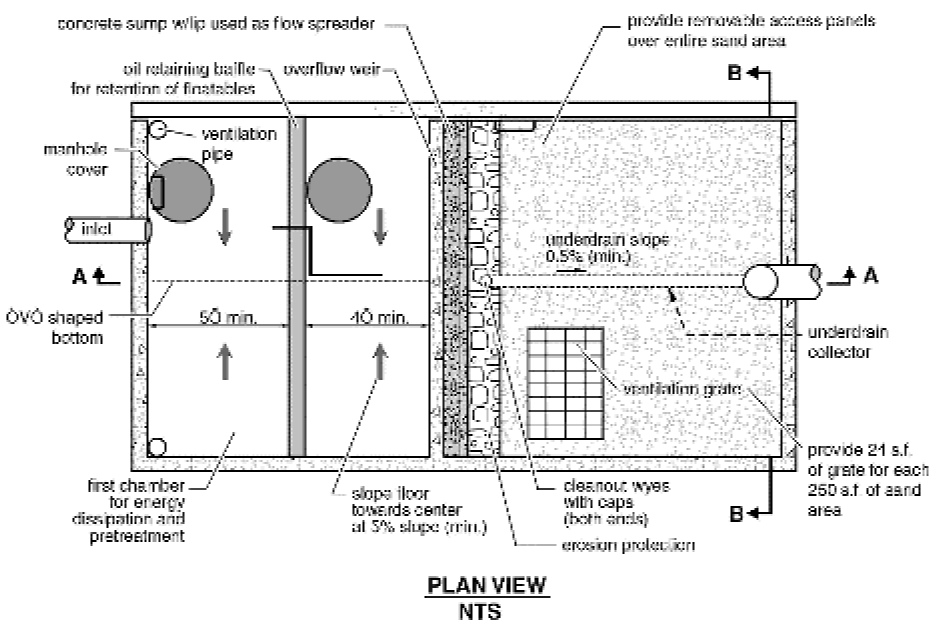
Sand and Organic Filters

**Postconstruction Storm Water Management
in New Development and Redevelopment**

Description

Sand filters are usually two-chambered storm water practices; the first is a settling chamber, and the second is a filter bed filled with sand or another filtering media. As storm water flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as storm water flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and Multi-Chamber Treatment Train. All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).



Schematic of a sand filter (Source: King County, Washington, 2000)

Applicability

Sand filters can be applied in most regions of the country and on most types of sites. Some restrictions at the site level, however, might restrict the use of sand filters as a storm water management practice (see Siting and Design Considerations).

Regional Applicability

Although sand filters can be used in both cold and arid climates, some design modifications might be necessary (See Siting and Design Considerations).

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface is present. Sand filters in general are good options in these areas because they consume little space. Underground and perimeter sand filters in particular are well suited to the ultra-urban setting because they consume no surface space.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. These areas include commercial nurseries, auto recycle facilities, commercial parking lots, fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/unloading facilities, public works storage areas, hazardous materials generators (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing/steam cleaning facilities. Sand filters are an excellent option to treat runoff from storm water hot spots because storm water treated by sand filters has no interaction with, and thus no potential to contaminate, the groundwater.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Sand filters are a good option to achieve water quality goals in retrofit studies where space is limited because they consume very little surface space and have few site restrictions. It is important to note, however, that sand filters cannot treat a very large drainage area. Using small-site BMPs in a retrofit may be the only option for a retrofit study in a highly urbanized area, but it is expensive to treat the drainage area of an entire watershed using many small-site practices, as opposed to one larger facility such as a pond.

Cold Water (Trout) Streams

Some species in cold water streams, notably trout, are extremely sensitive to changes in temperature. To protect these resources, designers should avoid treatment practices that increase the temperature of the storm water runoff they treat. Sand filters can be a good treatment option for cold water streams. In some storm water treatment practices, particularly wet ponds, runoff is warmed by the sun as it resides in the permanent pool. Surface sand filters are typically not designed with a permanent pool, although there is ponding in the sedimentation chamber and above the sand filter. Designers may consider shortening the detention time in cold water watersheds. Underground and perimeter sand filter designs have little potential for warming because these practices are not exposed to the sun.

Siting and Design Considerations

In addition to the broad applicability issues described above, designers need to consider conditions at the site level and need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Siting Considerations

Some considerations when selecting a storm water management practice are the drainage area the practice will need to treat, the slopes both at the location of the practice and draining to it, soil and subsurface conditions, and the depth of the seasonably high ground water table. Although sand filters are relatively versatile, some site restrictions such as available head might limit their use.

Drainage Area

Sand filters are best applied on relatively small sites (up to 10 acres for surface sand filters and closer to 2 acres for perimeter or underground filters [MDE, 2000]). Filters have been used on larger drainage areas, of up to 100 acres, but these systems can clog when they treat larger drainage areas unless adequate measures are provided to prevent clogging, such as a larger sedimentation chamber or more intensive regular maintenance.

Slope

Sand filters can be used on sites with slopes up to about 6 percent. It is challenging to use most sand filters in very flat terrain because they require a significant amount of elevation drop, or head (about 5 to 8 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

Soils/Topography

When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that storm water never infiltrates into the soil or interacts with the ground water. Alternatively, sand filters can be designed as pretreatment for an infiltration practice, where soils do play a role.

Ground Water

Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high ground water table. This design feature prevents both structural damage to the filter and possibly, though unlikely, ground water contamination.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. Some features, however, should be incorporated into most designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment is a critical component of any storm water management practice. In sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. In this chamber, the coarsest particles settle out and thus do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential of these sediments to clog the filter. Designers should provide at least 25 percent of the water quality volume in a dry or wet sedimentation chamber as pretreatment to the filter system. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½ inch of runoff over the entire drainage area to the practice.

The area of the sedimentation chamber may be determined based on the Camp-Hazen equation, as adapted by the Washington State Department of Ecology (Washington State DOE, 1992). This equation can be expressed as:

$A_s = (Q_o/W)\mathit{ln}(1\text{-}E)$

where:

A_s = surface area (ft^2);

Q_o = discharge rate from basin (water quality volume/detention time);

W = particle settling velocity (ft/s);

[CWP (1996) used a settling of 0.0004 ft/s for drainage areas greater than 75% impervious and 0.0033 ft/s for drainage areas less than or equal to 75% impervious to account for the finer particles that erode from pervious surfaces.]

E = removal efficiency fraction (usually assumed to be about 0.9(90%)).

Using the simplifying assumption of a 24-hour detention time, CWP (1996) reduced the above equation to

A_s = 0.066WTV (>75%)

A_s = 0.0081WTV (< or = 75%)

where

WTV = water quality volume (ft^3), or the volume of storm water to be treated by the practice.

<u>Treatment</u>

Treatment design features help enhance the ability of a storm water management practice to remove pollutants. In filtering systems, designers should provide at least 75 percent of the water quality volume in the practice (including both the sand chamber and the sediment chamber). In sand filters, designers should select a medium sand as the filtering medium.

The filter bed should be sized using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. The resulting equation, as derived by the city of Austin, Texas, (1996), is

AF = WTV d/[k t (h+d)]

where

AF = area of the filter bed (ft^2);

d = depth of the filter bed (ft; usually about 1.5 feet, depending on the design);

k = coefficient of permeability of the filtering medium (ft/day);

t = time for the water quality volume to filter through the system (days; usually assumed to be 1.67 days); and

h = average water height above the sand bed (ft; assumed to be one-half of the maximum head).

Typical values for k, as assembled by CWP (1996), are shown in Table 1.

Table 1: Coefficient of permeability values for storm water filtering practices (CWP, 1996)

Filter Medium	**Coefficient of Permeability (ft/day)**
Sand	3.5
Peat/Sand	2.75
Compost	8.7

Conveyance

Conveyance of storm water runoff into and through a storm water practice is a critical component of any storm water management practice. Storm water should be conveyed to and from practices safely and in a manner that minimizes erosion potential. Ideally, some storm water treatment can be achieved during conveyance to and from the practice.

Typically, filtering practices are designed as "off-line" systems, meaning that they have the smaller water quality volume diverted to them only during larger storms, using a flow splitter, which is a structure that bypasses larger flows to the storm drain system or to a stabilized channel. One exception is the perimeter filter; in this design, all flows enter the system, but larger flows overflow to an outlet chamber and are not treated by the practice.

All filtering practices, with the exception of exfilter designs (see Design Variations) are designed with an under drain below the filtering bed. An under drain is a perforated pipe system in a gravel bed, installed on the bottom of filtering practices and used to collect and remove filtered runoff.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. Designers should provide maintenance access to filtering systems. In underground sand filters, confined space rules defined by the Occupational Safety and Health Administration (OSHA) need to be addressed.

Landscaping

Landscaping can add to both the aesthetic value and the treatment ability of storm water practices. In sand filters, little landscaping is generally used on the practice, although surface sand filters and organic media filters may be designed with a grass cover on the surface of the filter. In all filters, designers need to ensure that the contributing drainage has dense vegetation to reduce sediment loads to the practice.

Design Variations

As mentioned earlier in this fact sheet, there are five basic storm water filter designs--surface sand filter, underground filter, perimeter filter (also known as the "Delaware" filter), organic media filter, and Multi-Chamber Treatment Train. Other design variations can incorporate design features to recharge ground water or to meet the design challenges of cold or arid climates.

Surface Sand Filter

The surface sand filter is the original sand filter design. In this practice both the filter bed and the sediment chamber are aboveground. The surface sand filter is designed as an off-line practice, where only the water quality volume is directed to the filter. The surface sand filter is the least expensive filter option and has been the most widely used.

Underground Sand Filter

The underground sand filter is a modification of the surface sand filter, where all of the filter components are underground. Like the surface sand filter, this practice is an off-line system that receives only the smaller water quality events. Underground sand filters are expensive to construct but consume very little space. They are well suited to highly urbanized areas.

Perimeter Sand Filter

The perimeter sand filter also includes the basic design elements of a sediment chamber and a filter bed. In this design, however, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is the only filtering option that is on-line, with all flows entering the system but larger events bypassing treatment by entering an overflow chamber. One major advantage to the perimeter sand filter design is that it requires little hydraulic head and thus is a good option in areas of low relief.

Organic Media Filter

Organic media filters are essentially the same as surface filters, with the sand medium replaced with or supplemented by another medium. Two examples are the peat/sand filter (Galli, 1990) and the compost filter system (CSF, 1996). The assumption is that these systems will have enhanced pollutant removal for many compounds because of the increased cation exchange capacity achieved by increasing the organic matter.

Multi-Chamber Treatment Train

The Multi-Chamber Treatment Train (Robertson et al., 1995) is essentially a "deluxe sand filter." This underground system consists of three chambers. Storm water enters into the first chamber, where screening occurs, trapping large sediments and releasing highly volatile materials. The second chamber provides settling of fine sediments and further removal of volatile compounds and also floatable hydrocarbons through the use of fine bubble diffusers and sorbent pads. The final chamber provides filtration by using a sand and peat mixed medium for reduction of the remaining pollutants. The top of the filter is covered by a filter fabric that evenly distributes the water volume and prevents channelization. Although this practice can achieve very high pollutant removal rates, it might be prohibitively expensive in many areas and has been implemented only on an experimental basis.

Exfiltration/Partial Exfiltration

In exfilter designs, all or part of the under drain system is replaced with an open bottom that allows infiltration to the ground water. When the under drain is present, it is used as an overflow device in case the filter becomes clogged. These designs are best applied in the same soils where infiltration practices are used (see Infiltration Basin and Infiltration Trench fact sheets).

Regional Variations

Arid Climates

Filters have not been widely used in arid climates. In these climates, however, it is probably necessary to increase storage in the sediment chamber to account for high sediment loads. Designers should consider increasing the volume of the sediment chamber to up to 40 percent of the water quality volume.

Cold Climates

In cold climates, filters can be used, but surface or perimeter filters will not be effective during the winter months, and unintended consequences might result from a frozen filter bed. Using alternative conveyance measures such as a weir system between the sediment chamber and filter bed may avoid freezing associated with the traditional standpipe. Where possible, the filter bed should be below the frost line. Some filters, such as the peat/sand filter, should be shut down during the winter. These media will become completely impervious during freezing conditions. Using a larger under drain system to encourage rapid draining during the winter months may prevent freezing of the filter bed. Finally, the sediment chamber should be larger in cold climates to account for road sanding (up to 40 percent of the water quality volume).

Limitations

Sand filters can be used in unique conditions where many other storm water management practices are inappropriate, such as in karst (i.e., limestone) topography or in highly urbanized settings. There are several limitations to these practices, however. Sand filters cannot control floods and generally are not designed to protect stream channels from erosion or to recharge the ground water. In addition, sand filters require frequent maintenance, and underground and perimeter versions of these practices are easily forgotten because they are out of sight. Perhaps one of the greatest limitations to sand filters is that they cannot be used to treat large drainage areas. Finally, surface sand filters are generally not aesthetically pleasing management practices. Underground and perimeter sand filters are not visible, and thus do not add or detract from the aesthetic value of a site.

Maintenance Considerations

Intense and frequent maintenance and inspection practices are needed for filter systems. Table 2 outlines some of these requirements.

Table 2: Typical maintenance/inspection activities for filtration systems (Adapted from WMI, 1997; CWP, 1997)

Activity	Schedule
• Ensure that contributing area, filtering practice, inlets, and outlets are clear of debris. • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Check to ensure that the filter surface is not clogging (also after moderate and major storms). • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • If a permanent pool is present, ensure that the chamber does not leak and that normal pool level is retained.	Monthly
• Replace sorbent pillows (Multi-Chamber Treatment Train only).	Biannual
• Check to see that the filter bed is clean of sediments, and the sediment chamber is no more than one-half full of sediment. Remove sediment if necessary. • Make sure that there is no evidence of deterioration, sailing, or cracking of concrete. • Inspect grates (if used). • Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damaged structural parts. • Stabilize any eroded areas. • Ensure that flow is not bypassing the facility. • Ensure that no noticeable odors are detected outside the facility.	Annual

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals: flood control, channel protection, ground water recharge, and pollutant removal. Filtering practices are for the most part adapted only to provide pollutant removal.

Ground Water Recharge

In exfilter designs, some ground water recharge can be provided; however, none of the other sand filter designs can provide recharge.

Pollutant Removal

Sand filters are effective storm water management practices for pollutant removal. Removal rates for all sand filters and organic filters are presented in Table 3. With the exception of nitrates, which appear to be exported from filtering systems, they perform relatively well at removing pollutants. The export of nitrates from filters may be caused by mineralization of organic nitrogen in the filter bed. Table 3 shows typical removal efficiencies for sand filters.

Table 3: Sand filter removal efficiencies (percent)

	Sand Filters (Schueler, 1997)	Peat/Sand Filter (Curran, 1996)	Compost Filter System		Multi-Chamber Treatment Train		
			Stewart, 1992	Leif, 1999	Pitt et al., 1997	Pitt, 1996	Greb et al., 1998
TSS	87	66	95	85	85	83	98
TP	51	51	41	4	80	-	84
TN	44	47	-	-	-	-	-
Nitrate	-13	22	-34	-95	-	14	-
Metals	34-80	26-75	61-88	44-75	65-90	91-100	83-89
Bacteria	55	-	-	-	-	-	-

From the few studies available, it is difficult to determine if organic filters necessarily have higher removal efficiencies than sand filters. The Multi-Chamber Treatment Train appears to have high pollutant removal for some constituents, although these data are based on only a handful of studies. The siting and design criteria presented in this fact sheet reflect the best current information and experience to improve the performance of sand filters. A recent joint project of the American Society of Civil Engineers (ASCE) and the U.S. EPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of storm water practices that includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. For more information on this database, access the ASCE web page at *http://www.asce.org*.

Cost Considerations

There are few consistent data on the cost of sand filters, largely because, with the exception of Austin, Texas, Alexandria, Virginia, and Washington, D.C., they have not been widely used. Furthermore, filters have such varied designs that it is difficult to assign a cost to filters in general. A study by Brown and Schueler (1997) was unable to find a statistically valid relationship between the volume of water treated in a filter and the cost of the practice, but

typical total cost of installation ranged between $2.50 and $7.50 per cubic foot of storm water treated, with an average cost of about $5 per cubic foot. (This estimate includes approximately 25 percent contingency costs beyond the construction costs reported). The cost per impervious acre treated varies considerably depending on the region and design used (see Table 4). It is important to note that, although underground and perimeter sand filters can be more expensive than surface sand filters, they consume no surface space, making them a relatively cost-effective practice in ultra-urban areas where land is at a premium.

Table 4: Construction costs for various sand filters (Source: Schueler, 1994)

Region (Design)	Cost/Impervious Acre
Delaware (Perimeter)	$10,000
Alexandria, VA (Perimeter)	$23,500
Austin, TX (<2 acres) (Surface)	$16,000
Austin, TX (>5 acres) (Surface)	$3,400
Washington, DC (underground)	$14,000
Denver, CO	$30,000–$50,000
Multi-Chamber Treatment Train	$40,000–$80,000

Information Resources

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Appendix I. Filter removal efficiency data

Filter Removal Efficiencies							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Practice Type**
Bell et al., 1995	79	65.5	47	-53.3	25–91	-	perimeter sand filter
Horner and Horner, 1995	83	46.3	-	-	22–33	-	perimeter sand filter
Horner and Horner, 1995	8	20	-	-	31–69	-	perimeter sand filter
Harper and Herr, 1993	98	61	-	27	37–89	-	surface sand filter
Welborn and Veenhuis, 1987	78	27	27	-100	33–60	81	surface sand filter
City of Austin, TX, 1990	75	59	44	-13	34–67	36	surface sand filter
City of Austin, TX, 1990	92	80	71	23	84–91	83	surface sand filter
City of Austin, TX, 1990	86	19	31	-5	33–71	37	surface sand filter
City of Austin, TX, 1990	87	61	32	-79	60-86	37	surface sand filter
Barton Springs/Edwards Aquifer Conservation District, 1996	81	39	13	-11	58–79	-	vertical sand filter
Barton Springs/Edwards Aquifer Conservation District, 1996	55	45	15	-87	58–60	-	vertical sand filter
Stewart, 1992	95	41	-	-34	61–87	-	organic filter
Curran, 1996	66	51	47	22	26–75	-	organic filter

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Storm Water Wetland

Postconstruction Storm Water Management in New Development and Redevelopment

Description

A storm water wetland detains storm water, removes pollutants, and provides habitat and aesthetic benefits (Source: The Bioengineering Group, Inc., no date)

Storm water wetlands (a.k.a. constructed wetlands) are structural practices similar to wet ponds (see Wet Pond fact sheet) that incorporate wetland plants into the design. As storm water runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the practice. Wetlands are among the most effective storm water practices in terms of pollutant removal and they also offer aesthetic value. Although natural wetlands can sometimes be used to treat storm water runoff that has been properly pretreated, storm water wetlands are fundamentally different from natural wetland systems. Storm water wetlands are designed specifically for the purpose of treating storm water runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life. Several design variations of the storm water wetland exist, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland.

A distinction should be made between using a constructed wetland for storm water management and diverting storm water into a natural wetland. The latter practice is not recommended because altering the hydrology of the existing wetland with additional storm water can degrade the resource and result in plant die-off and the destruction of wildlife habitat. In all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased storm water runoff. This is especially important because natural wetlands provide storm water and flood control benefits on a regional scale.

Applicability

Constructed wetlands are widely applicable storm water management practices. While they have limited applicability in highly urbanized settings and in arid climates, wetlands have few other restrictions.

Regional Applicability

Storm water wetlands can be applied in most regions of the United States, with the exception of arid climates. In arid and semi-arid climates, it is difficult to design any storm water practice that has a permanent pool. Because storm water wetlands are shallow, a relatively large area is subject to evaporation relative, to the volume of the practice. This makes maintaining the permanent pool in wetlands both more challenging and more important than maintaining the pool of a wet pond (see Wet Pond fact sheet).

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. It is difficult to use wet ponds in the ultra-urban environment because of the land area each wetland consumes. They can, however, be used in an ultra-urban environment if a relatively large area is available downstream of the site.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. A typical example is a gas station. Wetlands can accept runoff from storm water hot spots, but need significant separation from ground water if they will be used for this purpose. Caution also needs to be exercised, if these practices are designed to encourage wildlife use, to ensure that pollutants in storm water runoff do not work their way through the food chain of organisms living in or near the wetland.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. When retrofitting an entire watershed, storm water wetlands have the advantage of providing both educational and habitat value. One disadvantage to wetlands, however, is the difficulty of storing large amounts of runoff without consuming a large amount of land. It is also possible to incorporate wetland elements into existing practices, such as wetland plantings (see Wet Pond and Dry Extended Detention Pond fact sheets)

Cold Water (Trout) Streams

Wetlands pose a risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince George's County, Maryland, investigated the thermal impacts of a wide range of storm water management practices (Galli, 1990). In this study, only one wetland was investigated, which was an extended detention wetland (see Design Variations). The practice increased the average temperature of storm water runoff that flowed through the practice by about 3°F. As a result, it is likely that wetlands increase water temperature.

Siting and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Siting Considerations

In addition to the restrictions and modifications to adapting storm water wetlands to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting wetlands.

Drainage Area

Wetlands need sufficient drainage area to maintain the permanent pool. In humid regions, this is typically about 25 acres, but a greater area may be needed in regions with less rainfall.

Slope

Wetlands can be used on sites with an upstream slope of up to about 15 percent. The local slope should be relatively shallow, however. While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 3 to 5 feet).

Soils/Topography

Wetlands can be used in almost all soils and geology, with minor design adjustments for regions of karst (i.e. limestone) topography (see Design Considerations).

Ground Water

Unless they receive hot spot runoff, wetlands can often intersect the ground water table. Some research suggests that pollutant removal is reduced when ground water contributes substantially to the pool volume (Schueler, 1997b). It is assumed that wetlands would have a similar response.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most wetland designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In wetlands, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10 percent of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Treatment

Treatment design features help enhance the ability of a storm water management practice to remove pollutants. The purpose of most of these features is to increase the amount of time and flowpath by which storm water remains in the wetland. Some typical design features include

- The surface area of wetlands should be at least 1 percent of the drainage area to the practice.
- Wetlands should have a length-to-width ratio of at least 1.5:1. Making the wetland longer than it is wide helps prevent "short circuiting" of the practice.
- Effective wetland design displays "complex microtopography." In other words, wetlands should have zones of both very shallow (<6 inches) and moderately shallow (<18 inches) wetlands incorporated, using underwater earth berms to create the zones. This design will

provide a longer flow path through the wetland to encourage settling, and it provides two depth zones to encourage plant diversity.

Conveyance

Conveyance of storm water runoff into and through a storm water management practice is a critical component of any practice. Storm water should be conveyed to and from practices safely and to minimize erosion potential. The outfall of pond systems should always be stabilized to prevent scour. In addition, an emergency spillway should be provided to safely convey large flood events. To help mitigate warming at the outlet channel, designers should provide shade around the channel at the pond outlet.

Maintenance Reduction

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In wetlands, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wet ponds is clogging of the outlet. Wetlands should be designed with a nonclogging outlet such as a reverse-slope pipe or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris. Another general rule is that no orifice should be less than 3 inches in diameter. Smaller orifices are generally more susceptible to clogging, without specific design considerations to reduce this problem. Another feature that can help reduce the potential for clogging of the outlet is to incorporate a small pool, or "micropool" at the outlet.

Design features are also incorporated to ease maintenance of both the forebay and the main pool of wetlands. Wetlands should be designed with a maintenance access to the forebay to ease this relatively routine (5- to 7-year) maintenance activity. In addition, the permanent pool should have a pond drain to draw down the pond for the more infrequent dredging of the main cell of the wetland.

Landscaping

Landscaping of wetlands can make them an asset to a community and can also enhance the pollutant removal of the practice. In wetland systems, landscaping is an integral part of the design. To ensure the establishment and survival of wetland plants, a landscaping plan should provide detailed information about the plants selected, when they will be planted, and a strategy for maintaining them. The plan should detail wetland plants, as well as vegetation to be established adjacent to the wetland.

A variety of techniques can be used to establish wetland plants. The most effective techniques are the use of nursery stock as dormant rhizomes, live potted plants, and bare rootstock. A "wetland mulch," soil from a natural wetland or a designed "wetland mix," can be used to supplement wetland plantings or alone to establish wetland vegetation. Wetland mulch carries with it the seed bank from the original wetland, and can help to enhance diversity in the wetland. The least expensive option to establish wetlands is to allow the wetland to colonize itself. One disadvantage to this last technique is that invasive species such as cattails or Phragmites may dominate the wetland.

When developing a plan for wetland planting, care needs to be taken to ensure that plants are established in the proper depth and within the planting season. This season varies regionally, and is generally between 2 and 3 months long in the spring to early summer. Plant lists are available for various regions of the United States through wetland nurseries, extension services, and conservation districts.

Design Variations

There are several variations of the wetland design. The designs are characterized by the volume of the wetland in deep pool, high marsh, and low marsh, and whether the design allows for detention of small storms above the wetland surface. Other design variations help to make wetland designs practical in cold climates.

Shallow Marsh

In the shallow marsh design, most of the wetland volume is in the relatively shallow high marsh or low marsh depths. The only deep portions of the shallow wetland design are the forebay at the inlet to the wetland and the micropool at the outlet. One disadvantage to this design is that, since the pool is very shallow, a large amount of land is typically needed to store the water quality volume (i.e., the volume of runoff to be treated in the wetland).

Extended Detention Wetland

This design is the same as the shallow marsh, with additional storage above the surface of the marsh. Storm water is temporarily ponded above the surface in the extended detention zone for between 12 and 24 hours. This design can treat a greater volume of storm water in a smaller space than the shallow wetland design. In the extended detention wetland option, plants that can tolerate wet and dry periods should be specified in the extended detention zone.

Pond/Wetland System

The pond/wetland system combines the wet pond (see Wet Pond fact sheet) design with a shallow marsh. Storm water runoff flows through the wet pond and into the shallow marsh. Like the extended detention wetland, this design requires less surface area than the shallow marsh because some of the volume of the practice is in the relatively deep (i.e., 6–8 feet) pond.

Pocket Wetland

This design is very similar to the pocket pond (see Wet Pond fact sheet). In this design, the bottom of the wetland intersects the ground water, which helps to maintain the permanent pool. Some evidence suggests that ground water flows may reduce the overall effectiveness of storm water management practices (Schueler, 1997b). This option may be used when there is not significant drainage area to maintain a permanent pool.

Gravel-Based Wetlands

In this design, runoff flows through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the rocks, as well as by pollutant uptake of the plants. This practice is fundamentally different from other wetland designs because, while most wetland designs behave like wet ponds with differences in grading and landscaping, gravel-based wetlands are more similar to a filtering system.

Regional Variations

<u>Cold Climates</u>

Cold climates present many challenges to designers of wetlands. During the spring snowmelt, a large volume of water runs off in a short time, carrying a relatively high pollutant load. In addition, cold winter temperatures may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting, as well as sediment loads from road sanding, may impact wetland vegetation.

One of the greatest challenges of storm water wetlands, particularly shallow marshes, is that much of the practice is very shallow. Therefore, much of the volume in the wetland can be lost as the surface of the practice freezes. One study found that the performance of a wetland system was diminished during the spring snowmelt because the outlet and surface of the wetland had frozen. Sediment and pollutants in snowmelt and rainfall events "skated" over the surface of the wetland, depositing at the outlet of the wetland. When the ice melted, this sediment was washed away by storm events (Oberts, 1994). Several design features can help minimize this problem, including:

- "On-line" designs allowing flow to move continuously can help prevent outlets from freezing.
- Wetlands should be designed with multiple cells, with a berm or weir separating each cell. This modification will help to retain storage for treatment above the ice layer during the winter season.
- Outlets that are resistant to freezing should be used. Some examples include weirs or pipes with large diameters.

The salt and sand used to remove ice from roads and parking lots may also create a challenge to designing wetlands in cold climates. When wetlands drain highway runoff, or parking lots, salt-tolerant vegetation, such as pickle weed or cord grass should be used. (Contact a local nursery or extension agency for more information in your region). In addition, designers should consider using a large forebay to capture the sediment from road sanding.

<u>Karst Topography</u>

In karst (i.e., limestone) topography, wetlands should be designed with an impermeable liner to prevent ground water contamination or sinkhole formation, and to help maintain the permanent pool.

Limitations

Some features of storm water wetlands that may make the design challenging include the following:

- Each wetland consumes a relatively large amount of space, making it an impractical option on many sites.
- Improperly designed wetlands can become a breeding area for mosquitoes.
- Wetlands require careful design and planning to ensure that wetland plants are sustained after the practice is in place.
- It is possible that storm water wetlands may release nutrients during the nongrowing season.
- Designers need to ensure that wetlands do not negatively impact natural wetlands or forest during the design phase.
- Wetlands consume a large amount of land. This characteristic may limit their use in areas where land values are high.

Maintenance Considerations

In addition to incorporating features into the wetland design to minimize maintenance, some regular maintenance and inspection practices are needed. Table 1 outlines these practices.

Table 1. Regular maintenance activities for wetlands (Source: Adapted from WMI, 1997, and CWP, 1998)

Activity	Schedule
• Replace wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second growing season.	One-time
• Inspect for invasive vegetation and remove where possible.	Semi-annual inspection
• Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and are operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes.	Frequent (3–4 times/year) maintenance
• Supplement wetland plants if a significant portion have not established (at least 50% of the surface area). • Harvest wetland plants that have been "choked out" by sediment build-up.	Annual maintenance (if needed)
• Remove sediment from the forebay.	5- to 7-year maintenance
• Monitor sediment accumulations, and remove sediment when the pool volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic.	20- to 50-year maintenance

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Wetlands can provide flood control, channel protection, and pollutant removal.

Flood Control

One objective of storm water management practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Wetlands can easily be designed for flood control by providing flood storage above the level of the permanent pool.

Channel Protection

When used for channel protection, wetlands have traditionally controlled the 2-year storm. It appears that this control has been relatively ineffective, and recent research suggests that control of a smaller storm may be more appropriate (MacRae, 1996).

Ground Water Recharge

Wetlands cannot provide ground water recharge. The build-up of debris at the bottom of the wetland prevents the movement of water into the subsoil.

Pollutant Removal

Wetlands are among the most effective storm water management practices at removing storm water pollutants. A wide range of research is available to estimate the effectiveness of wetlands. Wetlands have high pollutant removal rates, and are more effective than any other practice at removing nitrate and bacteria. Table 2 provides pollutant removal data derived from the Center for Watershed Protections's National Pollutant Removal Database for Stormwater Treatment Practices (Winer, 2000).

The effectiveness of wetlands varies considerably, but many believe that proper design and maintenance might help to improve their performance. The siting and design criteria presented in this sheet reflect the best current information and experience to improve the performance of wetlands. A recent joint project of the American Society of Civil Engineers (ASCE) and the U.S. EPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of storm water practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. More information on this database is available on the ASCE web page at http://www.asce.org.

Table 2. Typical Pollutant Removal Rates of Wetlands (%) (Winer, 2000)

Pollutant	Stormwater Treatment Practice Design Variation			
	Shallow Marsh	ED Wetland[1]	Pond/Wetland System	Submerged Gravel Wetland[1]
TSS	83±51	69	71±35	83
TP	43±40	39	56±35	64
TN	26±49	56	19±29	19
NOx	73±49	35	40±68	81
Metals	36–85	(-80)–63	0–57	21–83
Bacteria	76[1]	NA	NA	78

[1]Data based on fewer than five data points

Cost Considerations

Wetlands are relatively inexpensive storm water practices. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25 percent more expensive than storm water ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of wet ponds can be modified to estimate the cost of storm water wetlands using the equation:

$C = 30.6V^{0.705}$

where:

C = Construction, design, and permitting cost;

V = Wetland volume needed to control the 10-year storm (ft^3).

Using this equation, typical construction costs are the following:

$ 57,100 for a 1 acre-foot facility

$ 289,000 for a 10 acre-foot facility

$ 1,470,000 for a 100 acre-foot facility

Wetlands consume about 3 to 5 percent of the land that drains to them, which is relatively high compared with other storm water management practices. In areas where land value is high, this may make wetlands an infeasible option.

For wetlands, the annual cost of routine maintenance is typically estimated at about 3 percent to 5 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Wetlands are long-lived facilities (typically longer than 20 years). Thus, the initial investment into these systems may be spread over a relatively long time period.

Although no studies are available on wetlands in particular, there is some evidence to suggest that wet ponds may provide an economic benefit by increasing property values. The results of one study suggest that "pond frontage" property can increase the selling price of new properties by about 10 percent (USEPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25 percent when located near a wet pond (Emmerling-Dinovo, 1995). It is anticipated that well-designed wetlands, which incorporate additional aesthetic features, would have the same benefit.

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Grassed Swales

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Grassed swales can be used along roadsides and parking lots to collect and treat storm water runoff

The term swale (a.k.a. grassed channel, dry swale, wet swale, biofilter) refers to a series of vegetated, open channel management practices designed specifically to treat and attenuate storm water runoff for a specified water quality volume. As storm water runoff flows through these channels, it is treated through filtering by the vegetation in the channel, filtering through a subsoil matrix, and/or infiltration into the underlying soils. Variations of the grassed swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch. These designs incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

Applicability

Grassed swales can be applied in most situations with some restrictions. Swales are very well suited for treating highway or residential road runoff because they are linear practices.

Regional Applicability

Grassed swales can be applied in most regions of the country. In arid and semi-arid climates, however, the value of these practices needs to be weighed against the water needed to irrigate them.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Grassed swales are generally not well suited to ultra-urban areas because they require a relatively large area of pervious surfaces.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. A typical example is a gas station or convenience store. With the exception of the dry swale design (see Design Variations), hot spot runoff should not be directed toward grassed channels. These practices either infiltrate storm water or intersect the ground water, making use of the practices for hot spot runoff a threat to ground water quality.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural) put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. One retrofit opportunity using grassed swales modifies existing drainage ditches. Ditches have traditionally been designed only to convey storm water away from roads. In some cases, it may be possible to incorporate features to enhance pollutant removal or infiltration such as check dams (i.e., small dams along the ditch that trap sediment, slow runoff, and reduce the longitudinal slope). Since grassed swales cannot treat a large area, using this practice to retrofit an entire watershed would be expensive because of the number of practices needed to manage runoff from a significant amount of the watershed's land area.

Cold Water (Trout) Streams

Grassed channels are a good treatment option within watersheds that drain to cold water streams. These practices do not pond water for a long period of time and often induce infiltration. As a result, standing water will not typically be subjected to warming by the sun in these practices.

Siting and Design Considerations

In addition to the broad applicability concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice, while minimizing the maintenance burden.

Siting Considerations

In addition to considering the restrictions and adaptations of grassed swales to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, highly impermeable soils) might restrict the effectiveness of grassed channels.

<u>Drainage Area</u>

Grassed swales should generally treat small drainage areas of less than 5 acres. If the practices are used to treat larger areas, the flows and volumes through the swale become too large to design the practice to treat storm water runoff through infiltration and filtering.

<u>Slope</u>

Grassed swales should be used on sites with relatively flat slopes of less than 4 percent slope; 1 to 2 percent slope is recommended. Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtering in the swale.

<u>Soils / Topography</u>

Grassed swales can be used on most soils, with some restrictions on the most impermeable soils. In the dry swale (see Design Variations) a fabricated soil bed replaces on-site soils in order to ensure that runoff is filtered as it travels through the soils of the swale.

Ground Water

The depth to ground water depends on the type of swale used. In the dry swale and grassed channel options, designers should separate the bottom of the swale from the ground water by at least 2 ft to prevent a moist swale bottom, or contamination of the ground water. In the wet swale option, treatment is enhanced by a wet pool in the practice, which is maintained by intersecting the ground water.

Design Considerations

Although there are different design variations of the grassed swale (see Design Variations), there are some design considerations common to all three. One overriding similarity is the cross-sectional geometry of all three options. Swales should generally have a trapezoidal or parabolic cross section with relatively flat side slopes (flatter than 3:1). Designing the channel with flat side slopes maximizes the wetted perimeter. The wetted perimeter is the length along the edge of the swale cross section where runoff flowing through the swale is in contact with the vegetated sides and bottom of the swale. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage filtering and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope. The flat bottom of all three should be between 2–8 ft wide. The minimum width ensures a minimum filtering surface for water quality treatment, and the maximum width prevents braiding, the formation of small channels within the swale bottom.

Another similarity among all three designs is the type of pretreatment needed. In all three design options, a small forebay should be used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river run gravel, should be used as pretreatment for runoff entering the sides of the swale.

Two other features designed to enhance the treatment ability of grassed swales are a flat longitudinal slope (generally between 1 percent and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the velocity of flow in the channel. The dense vegetation also helps reduce velocities, protect the channel from erosion, and act as a filter to treat storm water runoff. During construction, it is important to stabilize the channel before the turf has been established, either with a temporary grass cover or with the use of natural or synthetic erosion control products.

In addition to treating runoff for water quality, grassed swales need to convey larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

Design Variations

The following discussion identifies three different variations of open channel practices, including the grassed channel, the dry swale, and the wet swale.

Grassed Channel

Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. Of all of the grassed swale options, grassed channels are the least expensive but also provide the least reliable pollutant removal. The best application of a grassed channel is as pretreatment to other structural storm water practices.

One major difference between the grassed channel and most of the other structural practices is the method used to size the practice. Most storm water management water quality practices are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel, on the other hand, is a flow-rate-based design. Based on the peak flow from the water quality storm (this varies from region to region, but a typical value is the 1-inch storm), the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in *Design of Storm Water Filtering Systems* (CWP, 1996).

Dry Swales

Dry swales are similar in design to bioretention areas (see Bioretention fact sheet). These designs incorporate a fabricated soil bed into their design. The existing soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is used under the soil bed. This system is a gravel layer that encases a perforated pipe. Storm water treated in the soil bed flows through the bottom into the underdrain, which conveys this treated storm water to the storm drain system. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal.

Wet Swales

Wet swales intersect the ground water and behave almost like a linear wetland cell (see Storm Water Wetland fact sheet). This design variation incorporates a shallow permanent pool and wetland vegetation to provide storm water treatment. This design also has potentially high pollutant removal. One disadvantage to the wet swale is that it cannot be used in residential or commercial settings because the shallow standing water in the swale is often viewed as a potential nuisance by homeowners and also breeds mosquitos.

Regional Variations

Cold Climates

In cold or snowy climates, swales may serve a dual purpose by acting as both a snow storage/treatment and a storm water management practice. This dual purpose is particularly relevant when swales are used to treat road runoff. If used for this purpose, swales should incorporate salt-tolerant vegetation, such as creeping bentgrass.

Arid Climates

In arid or semi-arid climates, swales should be designed with drought-tolerant vegetation, such as buffalo grass. As pointed out in the Applicability section, the value of vegetated practices for water quality needs to be weighed against the cost of water needed to maintain them in arid and semi-arid regions.

Limitations

Grassed swales have some limitations, including the following:

- Grassed swales cannot treat a very large drainage area.
- Wet swales may become a nuisance due to mosquito breeding.
- If designed improperly (e.g., if proper slope is not achieved), grassed channels will have very little pollutant removal.
- A thick vegetative cover is needed for these practices to function properly.

Maintenance Considerations

Maintenance of grassed swales mostly involves maintenance of the grass or wetland plant cover. Typical maintenance activities are included in Table 1.

Table 1. Typical maintenance activities for grassed swales (Source: Adapted from CWP, 1996)

Activity	Schedule
• Inspect pea gravel diaphragm for clogging and correct the problem. • Inspect grass along side slopes for erosion and formation of rills or gullies and correct. • Remove trash and debris accumulated in the inflow forebay. • Inspect and correct erosion problems in the sand/soil bed of dry swales. • Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established. • Replant wetland species (for wet swale) if not sufficiently established.	Annual (semi-annual the first year)
• Rototill or cultivate the surface of the sand/soil bed of dry swales if the swale does not draw down within 48 hours. • Remove sediment build-up within the bottom of the swale once it has accumulated to 25 percent of the original design volume.	As needed (infrequent)
• Mow grass to maintain a height of 3–4 inches	As needed (frequent seasonally)

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Grassed swales can be used to meet ground water recharge and pollutant removal goals.

Ground Water Recharge

Grassed channels and dry swales can provide some ground water recharge as infiltration is achieved within the practice. Wet swales, however, generally do not contribute to ground water recharge. Infiltration is impeded by the accumulation of debris on the bottom of the swale.

Pollutant Removal

Few studies are available regarding the effectiveness of grassed channels. In fact, only 9 studies have been conducted on all grassed channels designed for water quality (Table 2). The data suggest relatively high removal rates for some pollutants, but negative removals for some bacteria, and fair performance for phosphorous. One study of available performance data (Schueler, 1997) estimates the removal rates for grassed channels as:

Total Suspended Solids: 81%

Total Phosphorous: 29%

Nitrate Nitrogen: 38%

Metals: 14% to 55%

Bacteria: -50%

Table 2. Grassed swale pollutant removal efficiency data

Removal Efficiencies (% Removal)							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Type**
Goldberg 1993	67.8	4.5	-	31.4	42–62	-100	grassed channel
Seattle Metro and Washington Department of Ecology 1992	60	45	-	-25	2–16	-25	grassed channel
Seattle Metro and Washington Department of Ecology, 1992	83	29	-	-25	46–73	-25	grassed channel
Wang et al., 1981	80	-	-	-	70–80	-	dry swale
Dorman et al., 1989	98	18	-	45	37–81	-	dry swale
Harper, 1988	87	83	84	80	88–90	-	dry swale
Kercher et al., 1983	99	99	99	99	99	-	dry swale
Harper, 1988.	81	17	40	52	37–69	-	wet swale
Koon, 1995	67	39	-	9	-35 to 6	-	wet swale
Occoquan Watershed Monitoring Lab, 1983	-100	100	100	-	-100	-	drainage channel

Table 2. (continued)

Removal Efficiencies (% Removal)							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Type**
Yousef et al., 1985	-	8	13	11	14–29	-	drainage channel
Occoquan Watershed Monitoring Lab, 1983	-50	-9.1	18.2	-	-100	-	drainage channel
Yousef et al., 1985	-	19.5	8	2	41–90	-	drainage channel
Occoquan Watershed Monitoring Lab, 1983	31	-23	36.5	-	-100 to 33	-	drainage channel
Welborn and Veenhuis, 1987	0	-25	-25	-25	0	-	drainage channel
Yu et al., 1993	68	60	-	-	74	-	drainage channel
Dorman et al., 1989	65	41	-	11	14-55	-	drainage channel
Pitt and McLean, 1986	0	-	0	-	0	0	drainage channel
Oakland, 1983	33	-25	-	-	20–58	0	drainage channel
Dorman et al., 1989	-85	12	-	-100	14–88	-	drainage channel

While it is difficult to distinguish between different designs based on the small amount of available data, grassed channels generally have poorer removal rates than wet and dry swales, although wet swales appear to export soluble phosphorous (Harper, 1988; Koon, 1995). It is not clear why swales export bacteria. One explanation is that bacteria thrive in the warm swale soils. Another is that studies have not accounted for some sources of bacteria, such as local residents walking dogs within the grassed swale area.

Cost Considerations

Little data are available to estimate the difference in cost between various swale designs. One study (SWRPC, 1991) estimated the construction cost of grassed channels at approximately \$0.25 per ft^2. This price does not include design costs or contingencies. Brown and Schueler (1997) estimate these costs at approximately 32 percent of construction costs for most storm water management practices. For swales, however, these costs would probably be significantly higher since the construction costs are so low compared with other practices. A more realistic estimate would be a total cost of approximately \$0.50 per ft^2, which compares favorably with other storm water management practices.

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Grassed Filter Strip

Postconstruction Storm Water Management in New Development and Redevelopment

Description


Grassed filter strips protect water quality by filtering pollutants before they reach the water (Source: USDA, 1997)

Grassed filter strips (vegetated filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice, and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide relatively high pollutant removal. One challenge associated with filter strips, however, is that it is difficult to maintain sheet flow, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.

Applicability

Filter strips are applicable in most regions, but are restricted in some situations because they consume a large amount of space relative to other practices. Filter strips are best suited to treating runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. They are also ideal components of the "outer zone" of a stream buffer (see Buffer Zones fact sheet), or as pretreatment to a structural practice. This recommendation is consistent with recommendations in the agricultural setting that filter strips are most effective when combined with another practice (Magette et al., 1989). In fact, the most recent storm water manual for Maryland does not consider the filter strip as a treatment practice, but does offer storm water volume reductions in exchange for using filter strips to treat some of a site.

Regional Applicability

Filter strips can be applied in most regions of the country. In arid areas, however, the cost of irrigating the grass on the practice will most likely outweigh its water quality benefits.

Ultra-Urban Areas

Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Filter strips are impractical in ultra-urban areas because they consume a large amount of space.

Storm Water Hot Spots

Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in storm water. A typical example is a gas station. Filter strips should not receive hot spot runoff, because the practice encourages infiltration. In addition, it is questionable whether this practice can reliably remove pollutants, so it should definitely not be used as the sole treatment of hot spot runoff.

Storm Water Retrofit

A storm water retrofit is a storm water management practice (usually structural), put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. Filter strips are generally a poor retrofit option because they consume a relatively large amount of space and cannot treat large drainage areas.

Cold Water (Trout) Streams

Some cold water species, such as trout, are sensitive to changes in temperature. While some treatment practices, such as wet ponds (see Wet Ponds fact sheet), can warm storm water substantially, filter strips do not warm pond water on the surface for long periods of time and are not expected to increase storm water temperatures. Thus, these practices are good for protection of cold-water streams.

Siting and Design Considerations

Siting Considerations

In addition to the restrictions and modifications to adapting filter strips to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question. The following section provides basic guidelines for siting filter strips.

Drainage Area

Typically, filter strips are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area the practice treats but the length of flow leading to it. As storm water runoff flows over the ground's surface, it changes from sheet flow to concentrated flow. Rather than moving uniformly over the surface, the concentrated flow forms rivulets which are slightly deeper and cover less area than the sheet flow. When flow concentrates, it moves too rapidly to be effectively treated by a grassed filter strip. As a rule, flow concentrates within a maximum of 75 feet for impervious surfaces, and 150 feet for pervious surfaces (CWP, 1996). Using this rule, a filter strip can treat one acre of impervious surface per 580-foot length.

Slope

Filter strips should be designed on slopes between 2 and 6 percent. Greater slopes than this would encourage the formation of concentrated flow. Except in the case of very sandy or gravelly soil, runoff would pond on the surface on slopes flatter than 2 percent, creating potential mosquito breeding habitat.

Soils /Topography

Filter strips should not be used on soils with a high clay content, because they require some infiltration for proper treatment. Very poor soils that cannot sustain a grass cover crop are also a limiting factor.

Ground Water

Filter strips should be separated from the ground water by between 2 and 4 ft to prevent contamination and to ensure that the filter strip does not remain wet between storms.

Design Considerations

Filter strips appear to be a minimal design practice because they are basically no more than a grassed slope. However, some design features are critical to ensure that the filter strip provides some minimum amount of water quality treatment.

- A pea gravel diaphragm should be used at the top of the slope. The pea gravel diaphragm (a small trench running along the top of the filter strip) serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

- The filter strip should be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal in the practice. Typical water quality volumes are the runoff from a 1-inch storm or ½-inch of runoff over the entire drainage area to the practice.

- The filter strip should be at least 25 feet long to provide water quality treatment.

- Designers should choose a grass that can withstand relatively high velocity flows and both wet and dry periods.

- Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion.

Regional Variations

In cold climates, filter strips provide a convenient area for snow storage and treatment. If used for this purpose, vegetation in the filter strip should be salt-tolerant, (e.g., creeping bentgrass), and a maintenance schedule should include the removal of sand built up at the bottom of the slope. In arid or semi-arid climates, designers should specify drought-tolerant grasses (e.g., buffalo grass) to minimize irrigation requirements.

Limitations

Filter strips have several limitations related to their performance and space consumption:

- The practice has not been shown to achieve high pollutant removal.

- Filter strips require a large amount of space, typically equal to the impervious area they treat, making them often infeasible in urban environments where land prices are high.

- If improperly designed, filter strips can become a mosquito breeding ground.

- Proper design requires a great deal of finesse, and slight problems in the design, such as improper grading, can render the practice ineffective in terms of pollutant removal.

Maintenance Considerations

Filter strips require similar maintenance to other vegetative practices (see Grassed Swales fact sheet). These maintenance needs are outlined below. Maintenance is very important for filter strips, particularly in terms of ensuring that flow does not short circuit the practice.

Table 1. Typical maintenance activities for grassed filter strips (Source: CWP, 1996)

Activity	Schedule
• Inspect pea gravel diaphragm for clogging and remove built-up sediment. • Inspect vegetation for rills and gullies and correct. Seed or sod bare areas. • Inspect to ensure that grass has established. If not, replace with an alternative species.	Annual inspection (semi-annual the first year)
• Mow grass to maintain a 3–4 inch height	Regular (frequent)
• Remove sediment build-up within the bottom when it has accumulated to 25% of the original capacity.	Regular (infrequent)

Effectiveness

Structural storm water management practices can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. The first two goals, flood control and channel protection, require that a storm water practice be able to reduce the peak flows of relatively large storm events (at least 1- to 2-year storms for channel protection and at least 10- to 50-year storms for flood control). Filter strips do not have the capacity to detain these events, but can be designed with a bypass system that routes these flows around the practice entirely.

Filter strips can provide a small amount of ground water recharge as runoff flows over the vegetated surface and ponds at the toe of the slope. In addition, it is believed that filter strips can provide modest pollutant removal. Studies from agricultural settings suggest that a 15-foot-wide grass buffer can achieve a 50 percent removal rate of nitrogen, phosphorus, and sediment, and that a 100-foot buffer can reach closer to 70 percent removal of these constituents (Desbonette et al., 1994). It is unclear how these results can be translated to the urban environment, however. The characteristics of the incoming flows are radically different both in terms of pollutant concentration and the peak flows associated with similar storm events. To date, only one study (Yu et al., 1992) has investigated the effectiveness of a grassed filter strip to treat runoff from a large parking lot. The study found that the pollutant removal varied depending on the length of flow in the filter strip. The narrower (75-foot) filter strip had moderate removal for some pollutants and actually appeared to export lead, phosphorus, and nutrients (See Table 2).

Table 2. Pollutant removal of an urban vegetated filter strip (Source: Yu et al., 1993)

	Pollutant Removal (%)	
	75-Ft Filter Strip	150-Ft Filter Strip
Total suspended solids	54	84
Nitrate+nitrite	-27	20
Total phosphorus	-25	40
Extractable lead	-16	50
Extractable zinc	47	55

Cost Considerations

Little data are available on the actual construction costs of filter strips. One rough estimate can be the cost of seed or sod, which is approximately 30¢ per ft^2 for seed or 70¢ per ft^2 for sod. This amounts to between $13,000 and $30,000 per acre for a filter strip, or the same amount per impervious acre treated. This cost is relatively high compared with other treatment practices. However, the grassed area used as a filter strip may have been seeded or sodded even if it were not used for treatment. In these cases, the only additional costs are the design, which is minimal, and the installation of a berm and gravel diaphragm. Typical maintenance costs are about $350/acre/year (adapted from SWRPC, 1991). This cost is relatively inexpensive and, again, might overlap with regular landscape maintenance costs.

The true cost of filter strips is the land they consume, which is higher than for any other treatment practice. In some situations this land is available as wasted space beyond back yards or adjacent to roadsides, but this practice is cost-prohibitive when land prices are high and land could be used for other purposes.

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Runoff pretreatment practices

Catch Basin

Postconstruction Storm Water Management in New Development and Redevelopment

Description

A catch basin (a.k.a. storm drain inlet, curb inlet) is an inlet to the storm drain system that typically includes a grate or curb inlet and a sump to capture sediment, debris, and associated pollutants. They are also used in combined sewer overflow (CSO) watersheds to capture floatables and settle some solids. Catch basins act as pretreatment for other treatment practices by capturing large sediments. The performance of catch basins at removing sediment and other pollutants depends on the design of the catch basin (e.g., the size of the sump) and maintenance procedures to retain the storage available in the sump to capture sediment.

A worker inserts a catch basin insert for oil and grease, trash, debris, and sediment removal from storm water as it enters the storm drainage system (Source: AbTech Industries, 2001)

Applicability

Catch basins are used in drainage systems throughout the United States. However, many catch basins are not ideally designed for sediment and pollutant capture. Ideal application of catch basins is as pretreatment to another storm water management practice. Retrofitting existing catch basins may help to improve their performance substantially. A simple retrofit option is to ensure that all catch basins have a hooded outlet to prevent floatable materials, such as trash and debris, from entering the storm drain system.

Limitations

Catch basins have three major limitations, including:

- Even ideally designed catch basins cannot remove pollutants as well as structural storm water management practices, such as wet ponds, sand filters, and storm water wetlands.
- Unless frequently maintained, catch basins can become a source of pollutants through resuspension.
- Catch basins cannot effectively remove soluble pollutants or fine particles.

Siting and Design Considerations

The performance of catch basins is related to the volume in the sump (i.e., the storage in the catch basin below the outlet). Lager et al. (1997) described an "optimal" catch basin sizing criterion, which relates all catch basin dimensions to the diameter of the outlet pipe (D):

- The diameter of the catch basin should be equal to 4D.
- The sump depth should be at least 4D. This depth should be increased if cleaning is infrequent or if the area draining to the catch basin has high sediment loads.
- The top of the outlet pipe should be 1.5 D from the bottom of the inlet to the catch basin.

Catch basins can also be sized to accommodate the volume of sediment that enters the system. Pitt et al. (1997) propose a sizing criterion based on the concentration of sediment in storm water runoff. The catch basin is sized, with a factor of safety, to accommodate the annual sediment load in the catch basin sump. This method is preferable where high sediment loads are anticipated, and where the optimal design described above is suspected to provide little treatment.

The basic design should also incorporate a hooded outlet to prevent floatable materials and trash from entering the storm drain system. Adding a screen to the top of the catch basin would not likely improve the performance of catch basins for pollutant removal, but would help capture trash entering the catch basin (Pitt et al., 1997).

A variety of other materials may also be used to filter runoff entering the catch basin. These products are known as "catch basin inserts." There are two basic catch basin insert varieties. One insert option consists of a series of trays, with the top tray serving as an initial sediment trap, and the underlying trays composed of media filters. Another option uses filter fabric to remove pollutants from storm water runoff. These devices have a very small volume, compared to the volume of the catch basin sump, and would typically require very frequent sediment removal. Bench test studies found that a variety of options showed little removal of total suspended solids, partially due to scouring from relatively small (6-month) storm events (ICBIC, 1995).

One design adaptation of the standard catch basin is to incorporate infiltration through the catch basin bottom. Two challenges are associated with this design. The first is potential ground water impacts, and the second is potential clogging, preventing infiltration. Infiltrating catch basins should not be used in commercial or industrial areas, because of possible ground water contamination. While it is difficult to prevent clogging at the bottom of the catch basin, it might be possible to incorporate some pretreatment into the design.

Maintenance Considerations

Typical maintenance of catch basins includes trash removal if a screen or other debris capturing device is used, and removal of sediment using a vactor truck. Operators need to be properly trained in catch basin maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of GIS systems to track sediment collection and to optimize future catch basin cleaning efforts.

One study (Pitt, 1985) concluded that catch basins can capture sediments up to approximately 60 percent of the sump volume. When sediment fills greater than 60 percent of their volume, catch basins reach steady state. Storm flows can then resuspend sediments trapped in the catch basin, and will bypass treatment. Frequent clean-out can retain the volume in the catch basin sump available for treatment of storm water flows.

At a minimum, catch basins should be cleaned once or twice per year (Aronson et al., 1993). Two studies suggest that increasing the frequency of maintenance can improve the performance of catch basins, particularly in industrial or commercial areas. One study of 60 catch basins in Alameda County, California, found that increasing the maintenance frequency from once per year to twice per year could increase the total sediment removed by catch basins on an annual basis (Mineart and Singh, 1994). Annual sediment removed per inlet was 54 pounds for annual cleaning, 70 pounds for semi-annual and quarterly cleaning, and 160 pounds for monthly cleaning. For catch basins draining industrial uses, monthly cleaning increased total annual sediment collected to six times the amount collected by annual cleaning (180 pounds versus 30 pounds). These results suggest that, at least for industrial uses, more frequent cleaning of catch basins may improve efficiency. However, the cost of increased operation and maintenance costs needs to be weighed against the improved pollutant removal.

In some regions, it may be difficult to find environmentally acceptable disposal methods for collected sediments. The sediments may not always be land-filled, land-applied, or introduced into the sanitary sewer system due to hazardous waste, pretreatment, or ground water regulations. This is particularly true when catch basins drain runoff from hot spot areas.

Effectiveness

What is known about the effectiveness of catch basins is limited to a few studies. Table 1 outlines the results of some of these studies.

Table 1. Pollutant removal of catch basins (percent).

Study	Notes	TSS[a]	COD[a]	BOD[a]	TN[a]	TP[a]	Metals
Pitt et al., 1997	–	32	–		–	–	–
Aronson et al., 1983	Only very small storms were monitored in this study.	60–97	10–56	54–88	–	–	–
Mineart and Singh, 1994	Annual load reduction estimated based on concentrations and mass of catch basin sediment.	–	–	–	–	–	For Copper: 3–4% (Annual cleaning) 15% (Monthly cleaning)

[a] TSS=total suspended solids; COD=chemical oxygen demand; BOD=biological oxygen demand; TN=total nitrogen; TP=total phosphorus

Cost Considerations

A typical pre-cast catch basin costs between $2,000 and $3,000. The true pollutant removal cost associated with catch basins, however, is the long-term maintenance cost. A vactor truck, the most common method of catch basin cleaning, costs between $125,000 and $150,000. This initial cost may be high for smaller Phase II communities. However, it may be possible to share a vactor truck with another community. Typical vactor trucks can store between 10 and 15 cubic yards of material, which is enough storage for three to five catch basins with the "optimal" design and an 18-inch inflow pipe. Assuming semi-annual cleaning, and that the vactor truck could be filled and material disposed of twice in one day, one truck would be sufficient to clean between 750 and 1,000 catch basins. Another maintenance cost is the staff time needed to operate the truck. Depending on the regulations within a community, disposal costs of the sediment captured in catch basins may be significant.

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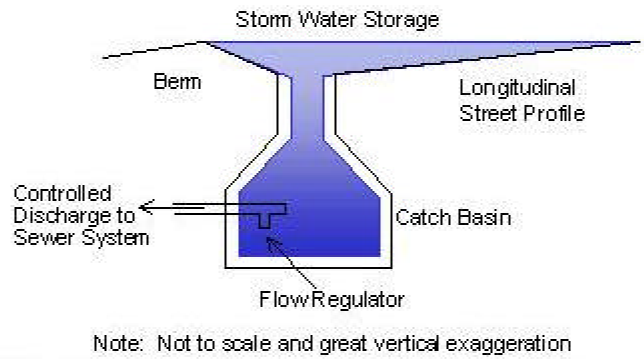
In-Line Storage

Postconstruction Storm Water Management in New Development and Redevelopment

Description

In-line storage refers to a number of practices designed to use the storage within the storm drain system to detain flows. While these practices can reduce storm peak flows, they are unable to improve water quality or protect downstream channels. Storage is achieved by placing devices in the storm drain system to restrict the rate of flow. Devices can slow the rate of flow by backing up flow, as in the case of a dam or weir, or through the use of vortex valves, devices that reduce flow rates by creating a helical flow path in the structure. A description of various flow regulators is included in Urbonas and Stahre (1990).



Catch basins can be equipped with flow restrictors to temporarily detain storm water in the conveyance system

Applicability

In-line storage practices serve the same purpose as traditional detention basins (see Dry Extended Detention Pond). These practices can act as a surrogate for aboveground storage when little space is available for aboveground storage facilities.

Limitations

In-line storage has several limitations, including:

- In-line storage practices only control flow, and thus are not able to improve the water quality of storm water runoff.
- If improperly designed, these practices may cause upstream flooding.

Siting and Design Considerations

Flow regulators cannot be applied to all storm drain systems. In older cities, the storm drainpipes may not be oversized, and detaining storm water within them would cause upstream flooding. Another important issue in siting these practices is the slope of the pipes in the system. In areas with very flat slopes, restricting flow within the system is likely to cause upstream flooding because introducing a regulator into the system will cause flows to back up a long distance before the regulator. In steep pipes, on the other hand, a storage flow regulator cannot utilize much of the storage available in the storm drain system.

Maintenance Considerations

Flow regulators require very little maintenance, because they are designed to be "self cleaning," much like the storm drain system. In some cases, flow regulators may be modified based on downstream flows, new connections to the storm drain, or the application of other flow regulators within the system. For some designs, such as check dams, regulations will require only moderate construction in order to modify the structure's design.

Effectiveness

The effectiveness of in-line storage practices is site-specific and depends on the storage available in the storm drain system. In one study, a single application was able to reduce peak flows by approximately 50 percent (VDCR, 1999).

Cost Considerations

Flow regulators are relatively low cost options, particularly since they require little maintenance and consume little surface area.

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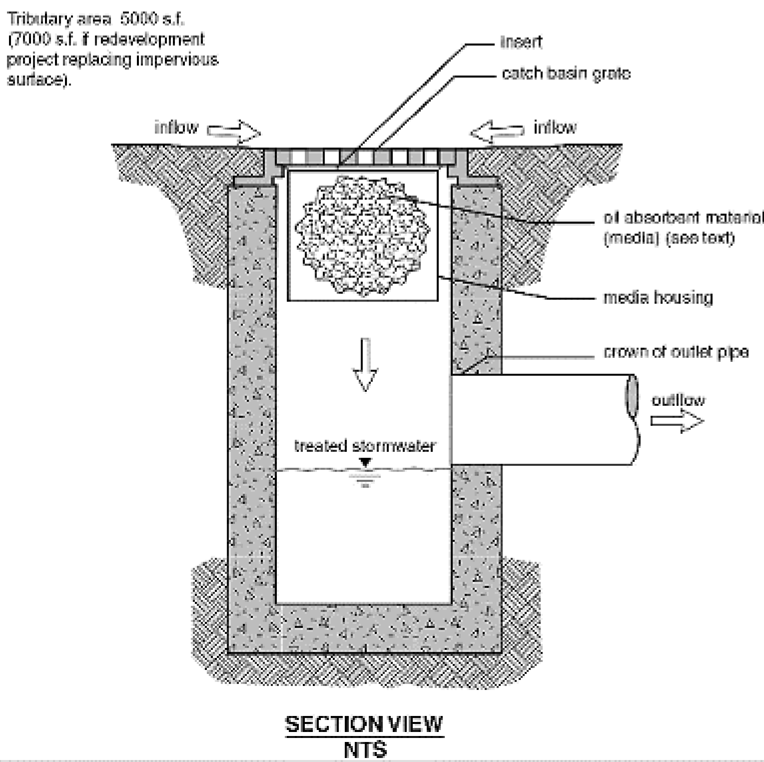
Manufactured Products for Storm Water Inlets

Postconstruction Storm Water Management in New Development and Redevelopment



The typical design of a catch basin insert is a set of filters that are specifically chosen to address the pollutants expected at that site (Source: King County, Washington, 2000)

Description

A variety of products for storm water inlets known as swirl separators, or hydrodynamic structures, have been widely applied in recent years. Swirl separators are modifications of the traditional oil-grit separator and include an internal component that creates a swirling motion as storm water flows through a cylindrical chamber. The concept behind these designs is that sediments settle out as storm water moves in this swirling path. Additional compartments or chambers are sometimes present to trap oil and other floatables. There are several different types of proprietary separators, each of which incorporates slightly different design variations, such as off-line application. Another common manufactured product is the catch basin insert. These products are discussed briefly in the Catch Basin fact sheet.

Applicability

Swirl separators are best installed on highly impervious sites. Because little data are available on their performance, and independently conducted studies suggest marginal pollutant removal, swirl separators should not be used as a stand-alone practice for new development. The best application of these products is as pretreatment to another storm water device, or in a retrofit situation where space is limited.

Limitations

Limitations to swirl separators include:

- Very little data are available on the performance of these practices, and independent studies suggest only moderate pollutant removal. In particular, these practices are ineffective at removing fine particles and soluble pollutants.
- The practice has a high maintenance burden (i.e., frequent cleanout).
- Swirl concentrators are restricted to small and highly impervious sites.

Siting and Design Considerations

The specific design of swirl concentrators is specified by product literature available from each manufacturer. For the most part, swirl concentrators are a rate-based design. That is, they are sized based on the peak flow of a specific storm event. This design contrasts with most other storm water management practices, which are sized based on capturing and storing or treating a specific volume. Sizing based on flow rate allows the practice to provide treatment within a much smaller area than other storm water management practices.

Maintenance Considerations

Swirl concentrators require frequent maintenance (typically quarterly). Maintenance is performed using a vactor truck, as is used for catch basins (see Catch Basin). In some regions, it may be difficult to find environmentally acceptable disposal methods. The sediments may not always be land-filled, land-applied, or introduced into the sanitary sewer system due to hazardous waste, pretreatment, or groundwater regulations. This is particularly true when catch basins drain runoff from hot spot areas.

Effectiveness

While manufacturers' literature typically reports removal rates for swirl separator design, there is actually very little independent data to evaluate the effectiveness of these products. Two studies investigated one of these products. Both studies reported moderate pollutant removal. While the product outperforms oil/grit separators, which have virtually no pollutant removal (Schueler, 1997), the removal rates are not substantially different from the standard catch basin. One long-term advantage of these products over catch basins is that, if they incorporate an off-line design, trapped sediment will not become resuspended. Data from two studies are presented below. Both of these studies are summarized in a Claytor (1999).

Table 1. Effectiveness of manufactured products for storm water inlets

Study	Greb et al., 1998	Labatiuk et al., 1997
Notes	Investigated 45 precipitation events over a 9-month period. Percent removal rates reflect overall efficiency, accounting for pollutants in bypassed flows.	Data represent the mean percent removal rate for four storm events.
TSS[a]	21	51.5
TDS[a]	-21	-
TP[a]	17	-
DP[a]	17	-
Pb[a]	24	51.2
Zn[a]	17	39.1
Cu[a]	-	21.5
PAH[a]	32	-
NO_2+NO_3[a]	5	-

[a] TSS=total suspended solids; TDS=total dissolved solids; TP=total phosphorus; DP=dissolved phosphorus; Pb=lead; Zn=zinc; Cu=copper; PAH=polynuclear aromatic hydrocarbons; NO_2+NO_3=nitrite+nitrate-nitrogen

Cost Considerations

A typical swirl separator costs between $5,000 and $35,000, or between $5,000 and $10,000 per impervious acre. This cost is within the range of some sand filters, which also treat highly urbanized runoff (see Sand Filters). Swirl separators consume very little land, making them attractive in highly urbanized areas.

The maintenance of these practices is relatively expensive. Swirl concentrators typically require quarterly maintenance, and a vactor truck, the most common method of cleaning these practices, costs between $125,000 and $150,000. This initial cost may be high for smaller Phase II communities. However, it may be possible to share a vactor truck with another community. Depending on the rules within a community, disposal costs of the sediment captured in swirl separators may be significant.

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Nonstructural BMPs

Experimental practices

Alum Injection

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Alum injection is the addition of alum (an aluminum sulfate salt) solution to storm water, causing fine particles to flocculate (i.e., gather together to form larger particles) and settle out. Other pollutants also can be scavenged. Alum injection can help meet downstream pollutant concentration loads by reducing the concentrations of fine particles and soluble phosphorus. Alum treatment systems generally consist of a flow-weighted dosing system designed to fit inside a storm sewer manhole, remotely located storage tanks to provide the doser with alum, and a downstream pond which allows the alum, pollutants, and sediments to settle out (Kurz, 1998). When alum is injected into storm water it forms harmless precipitates, aluminum phosphate and aluminum hydroxide. These precipitates combine with heavy metals and phosphorus, causing them to be deposited into the sediments in a stable, inactive state (WEF, 1992). The collected mass of alum precipitates, pollutants, and sediments is commonly referred to as floc.

Applicability

The injection of liquid alum into storm sewers has been used to reduce the water quality impacts of storm water runoff to lakes and receiving waterbodies, particularly to reduce high phosphorus levels. Because of high installation and operation costs, alum injection is best applied in situations where a large volume of water is stored in one area, as in the case of combined sewer overflow (CSO) storage areas at wastewater treatment plants. Alum treatment can also be implemented as a pretreatment step to further reduce turbidity and total suspended solids (TSS) (Kurz, 1998).

Siting and Design Considerations

Alum injection systems need to incorporate several design features to properly apply alum and dispose of the floc formed during the process. Dosage rates, which range from 5 to 10 mg of Al per liter, are determined on a flow-weighted basis during storm events (Harper, 1996). Other chemicals, such as lime, may also be added during the process to enhance the pollutant settling. (Often, the pH is raised to between 8 and 11). The design needs to incorporate a doser system, as well as sufficient chemical storage in tanks to minimize the frequency with which they need to be refilled.

Disposal of the floc that settles in the downstream basin is critical, because of the concentration of dissolved chemicals, and also because bacteria and viruses remain viable in the floc layer (Kurz, 1998). In addition to the settling pond, a separate floc collection pump-out facility should be installed to further reduce the chance of resuspension and transport of floc to receiving waterbodies. The pump disposes the floc into the sanitary sewer system or onto nearby upland areas or sludge drying beds. A permit will be required to pump to the sanitary sewer, however. The quantity of sludge produced at a site can be as much as 0.5 percent of the volume of water treated (Gibb et al., 1991).

Limitations

While alum shows some potential as a storm water treatment practice, it has several limitations, including:

- Alum injection is an experimental practice, and little is known about its long-term performance.
- In addition to maintenance, alum injection requires ongoing operation, unlike most other post-construction storm water treatment practices.
- While alum injection can reduce pollutant loads, it cannot control flows or protect downstream channels from erosion.
- Chemicals added during the alum injection process may have negative impacts on downstream waters.
- The precipitates from the alum increase the solids that must be disposed of from the treatment.

Maintenance Considerations

Operation and maintenance for alum treatment is critical. Some typical items include:

- There must be routine inspection and repair of equipment, including the doser and pump-out facility.
- A trained operator should be on-site to adjust the dosage of alum and other chemicals, and possibly to regulate flows through the basin.
- If floc is stored on-site in drying beds, it will need to be disposed of on a regular basis.
- The settling basin will need to be dredged periodically to dispose of accumulated floc.

Effectiveness

Limited performance data of alum injection is available in Table 1. One study (Harper and Herr, 1996) found high removal rates for TSS and fecal coliform bacteria. This study and another (Carr, 1998) showed mixed results on total phosphorus and ortho-phosphorus.

Table 1. Alum injection removal rates

Study	TSS	TP	Ortho-phosphorus	TN	Fecal Coliform Bacteria	Heavy Metals	Zinc	Ammonia
Harper and Herr, 1996	95–99	85–95	90–95	60–70	]99	50–90	-	-
Carr, 1998	-	37	42	52.2	-	-	41	24.5

Cost Considerations

Alum injection is a relatively expensive practice. Construction costs for alum treatment systems range from $135,000 to $400,000; the cost depends on the watershed size and the number of outfall locations treated. Generally, alum treatment is applied to large drainage areas. In one study (Kurz, 1998), an alum treatment system was a successful storm water retrofit for a 460-acre urbanized watershed in downtown Tampa. Operation and maintenance costs, which include routine and chemical inspections, range from $6,500 to $25,000 per year (Harper and Herr, 1996).

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On-lot Treatment

On-Lot Treatment

Postconstruction Storm Water Management in New Development and Redevelopment

Description

The term "on-lot treatment" refers to a series of practices that are designed to treat runoff from individual residential lots. The primary purpose of most on-lot practices is to manage rooftop runoff and, to a lesser extent, driveway and sidewalk runoff. Rooftop runoff, and particularly residential rooftop runoff, generally has low pollutant concentrations compared with other urban sources (Schueler, 1994b). The primary advantage of managing runoff from rooftops is to disconnect these impervious surfaces, reducing the effective impervious cover in a watershed. Many of the impacts of urbanization on the habitat and water quality of streams are related to the fundamental change in the hydrologic cycle caused by the increase of impervious cover in the landscape (Schueler, 1994a).

A rain barrel is used to collect rooftop runoff using a gutter/downspout system

Although there are a wide variety of on-lot treatment options, they can all be classified into one of three categories: 1) practices that infiltrate rooftop runoff; 2) practices that divert runoff or soil moisture to a pervious area; and 3) practices that store runoff for later use. The best option depends on the goals of a community, the feasibility at a specific site, and the preferences of the homeowner.

The practice most often used to infiltrate rooftop runoff is the dry well. In this design, the storm drain is directed to an underground rock-filled trench that is similar in design to an infiltration trench (see Infiltration Trench fact sheet). French drains or Dutch drains can also be used for this purpose. In these designs, the relatively deep dry well is replaced with a long trench with a perforated pipe within the gravel bed to distribute flow throughout the length of the trench.

Runoff can be diverted to a pervious area or to a treatment area using site grading, or channels and berms. Treatment options can include grassed swales, bioretention, or filter strips. The bioretention design can be simplified for an on-lot application by limiting the pre-treatment filter and in some cases eliminating the underdrain (see Bioretention fact sheet). Alternatively, rooftop runoff can simply be diverted to pervious lawn areas, as opposed to flowing directly to the street and thus to the storm drain system.

Practices that store rooftop runoff, such as cisterns and rain barrels, are the simplest in design of all of the on-lot treatment systems. Some of these practices are available commercially and can be applied in a wide variety of site conditions. Cisterns and rain barrels are particularly valuable in the arid southwest, where water is at a premium, rainfall is infrequent, and reuse for irrigation can save homeowners money.

Application

Some sort of on-lot treatment can be applied to almost all sites, with very few exceptions (e.g., very small lots or lots with no landscaping). Traditionally, on-site treatment of residential storm water runoff has been encouraged, but has not generally been an option to meet storm water requirements. There are currently at least two jurisdictions, however, who offer "credits" in exchange for the application of on-site storm water management practices. In Denver, Colorado, sites designed with methods to reduce "directly connected impervious cover," including disconnection of downspout runoff from the storm system, are permitted to use a lower site impervious area when computing the required storage of storm water facilities (DUDFCD, 1992). Similarly, new regulations for Maryland allow designers to subtract each rooftop that is disconnected from the total site impervious cover when calculating required storage in storm water management practices (MDE, 2000).

Siting and Design Considerations

Although most residential lots can incorporate on-lot treatment, the best option for a site depends on site design constraints and the preferences of the homeowner. On-lot infiltration practices have the same restrictions regarding soils as other infiltration practices (see Infiltration Basin and Infiltration Trench fact sheets). If other design practices are used, such as bioretention or grassed swales, they need to meet the siting requirements of those practices (see Bioretention and Grassed Swale fact sheets). Of all of the practices, cisterns and rain barrels have the fewest site constraints. In order for the practice to be effective, however, homeowners need to have a use for the water stored in the practice, and the design must accommodate overflow and winter freezing conditions. These practices are best suited to an individual who has some active interest in gardening or landscaping.

Although these practices are simple compared with many other post construction storm water practices, the design needs to incorporate the same basic elements of any storm water practice. Pretreatment is important for all of these practices to ensure that they do not become clogged with leaf debris. Infiltration practices may be preceded by a settling tank or, at a minimum, a grate or filter in the downspout to trap leaves and other debris. Rain barrels and cisterns also often incorporate some sort of pretreatment, such as a mesh filter at the top of the barrel or cistern.

Both infiltration practices and storage practices typically incorporate some type of bypass so that larger storms flow away from the house. In rain barrels or cisterns, this bypass may be a hose set at a high level of the practice and directed away from the practice and building foundation. These practices also include a hose set at the elevation of the bottom of the practice. The homeowner can use the practice to irrigate landscaping or for other uses by attaching this hose to a standard garden hose, and controlling flow with an adjustable valve. In infiltration practices the bypass may be an aboveground opening of the downspout. As on-lot practices, grassed swales and bioretention can be designed on-line. The design directs all flows to the management practice, but larger flows generally flow over the practice and are not treated.

One important design feature of infiltration practices is that the infiltration area must be located sufficiently far from the house's foundation to prevent undermining of the foundation or seepage into basements. The infiltration area should be separated from the house by at least 10 feet to prevent these problems.

Limitations

There are some limitations to the use of on-lot practices, including the following:

- These practices require some maintenance and require some effort on the part of the homeowner.
- For homeowners who do not enjoy landscaping, it may be difficult for them to find a use for water stored in a rain barrel or cistern, since the water is not potable.
- On small lots, some of these practices may be impractical.
- Even if applied to every home in a watershed, these practices would only treat a relatively small portion of the watershed imperviousness, which is largely composed of roads and parking areas (see Narrower Residential Streets and Green Parking fact sheets).

Maintenance Considerations

Bioretention areas, filter strips, and grassed swales require regular maintenance to ensure that the vegetation remains in good condition (see Bioretention; Grassed Filter Strip; and Grassed Swale fact sheets). Infiltration practices require regular removal of sediment and debris settled in the pretreatment area, and the media might need to be replaced if it becomes clogged (see Infiltration Trench fact sheet). Rain barrels and cisterns require minimal maintenance, but the homeowner needs to ensure that the hose remains elevated during the winter to prevent freezing and cracking. In addition, the tank needs to be cleaned out approximately once per year.

Effectiveness

Although the practices used for on-lot applications can have relatively high pollutant removals (see Infiltration Trench; Bioretention; Grassed Filter Strip; and Grassed Swale fact sheets), it is not clear that these pollutant removal rates can be realized with the relatively low pollutant concentrations entering the practices. Some data suggest that, at least for storm water ponds, there may be an "irreducible concentration" below which no further pollutant removal can be achieved (Schueler, 1996). Another benefit of many on-lot practices is that they generally promote ground water recharge, either directly through infiltration or indirectly by applying or directing runoff to pervious areas.

Cost Considerations

On a cost per unit area treated, on-lot practices are relatively expensive compared with other storm water treatment options. It is difficult to make this comparison, however, because the cost burden of on-lot practices is born directly by homeowners. Typical costs are $100 for a rain barrel and $200 for a dry well or French drain. For many of these practices, homeowners can reduce costs by making their own on-lot practice rather than purchasing a commercial product.

Some treatment practices, such as rain barrels and on-lot bioretention, offer additional benefits to the homeowner that may offset the cost of applying the practice. Similarly, maintenance costs are essentially free, with the exception of replacement of a dry well system, which may require outside help.

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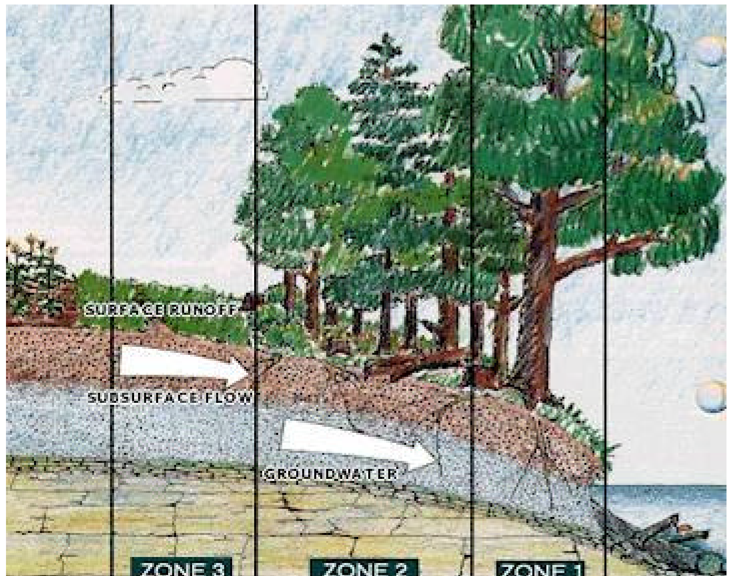
Better site design

Buffer Zones

Postconstruction Storm Water Management in New Development and Redevelopment

Description



Sketch of a typical riparian forest buffer (Source: Chesapeake Bay Program, 2000)

An aquatic buffer is an area along a shoreline, wetland, or stream where development is restricted or prohibited. The primary function of aquatic buffers is to physically protect and separate a stream, lake, or wetland from future disturbance or encroachment. If properly designed, a buffer can provide storm water management and act as a right-of-way during floods, sustaining the integrity of stream ecosystems and habitats. Technically, aquatic buffers are one type of conservation area that function as an integral part of the aquatic ecosystem and can also function as part of an urban forest.

The three types of buffers are water pollution hazard setbacks, vegetated buffers, and engineered buffers. Water pollution hazard setbacks are areas that separate a potential pollution hazard from a waterway. By providing setbacks from these areas in the form of a buffer, the potential for pollution can be reduced. Vegetated buffers are any number of natural areas that exist to divide land uses or provide landscape relief. Engineered buffers are areas specifically designed to treat storm water before it enters into a stream, lake, or wetland.

Applicability

Buffers can be applied to new development by establishing specific preservation areas and sustaining management through easements or community associations. For existing developed areas, an easement may be needed from adjoining landowners. A local ordinance can help set specific criteria for buffers to achieve storm water management goals.

In many regions of the country, the benefits of buffers are amplified if they are managed in a forested condition. In some settings, buffers can remove pollutants traveling in storm water or ground water. Shoreline and stream buffers situated in flat soils have been found to be effective in removing sediment, nutrients, and bacteria from storm water runoff and septic system effluent in a wide variety of rural and agricultural settings along the East Coast and with some limited capability in urban settings. Buffers can also provide wildlife habitat and recreation, and can be reestablished in urban areas as part of an urban forest.

Siting and Design Considerations

There are ten key criteria to consider when establishing a stream buffer:

- Minimum total buffer width
- Three-zone buffer system
- Mature forest as a vegetative target
- Conditions for buffer expansion or contraction
- Physical delineation requirements
- Conditions where buffer can be crossed
- Integrating storm water and storm water management within the buffer
- Buffer limit review
- Buffer education, inspection, and enforcement
- Buffer flexibility.

In general, a minimum base width of at least 100 feet is recommended to provide adequate stream protection. The three-zone buffer system, consisting of inner, middle, and outer zones, is an effective technique for establishing a buffer. The zones are distinguished by function, width, vegetative target, and allowable uses. The inner zone protects physical and ecological integrity and is a minimum of 25 feet plus wetland and critical habitats. The vegetative target consists of mature forest, and allowable uses are very restricted (flood controls, utility right-of-ways, footpaths, etc.).

The middle zone provides distance between upland development and the inner zone and is typically 50 to 100 feet, depending on stream order, slope, and 100-year floodplain. The vegetative target for this zone is managed forest, and usage is restricted to some recreational uses, some storm water BMPs, and bike paths. The outer zone functions to prevent encroachment and filter backyard runoff. The width is at least 25 feet and, while forest is encouraged, turfgrass can be a vegetative target. Uses for the outer zone are unrestricted and can include lawn, garden, compost, yard wastes, and most storm water BMPs.

For optimal storm water treatment, the following buffer designs are recommended. The buffer should be composed of three lateral zones: a storm water depression area that leads to a grass filter strip that in turn leads to a forested buffer. The storm water depression is designed to capture and store storm water during smaller storm events and bypass larger stormflows directly into a channel. The captured runoff within the storm water depression can then be spread across a grass filter designed for sheetflow conditions for the water quality storm. The grass filter then discharges into a wider forest buffer designed to have zero discharge of surface runoff to the stream (i.e., full infiltration of sheetflow).

Stream buffers must be highly engineered in order to satisfy these demanding hydrologic and hydraulic conditions. In particular, simple structures are needed to store, split, and spread surface runoff within the storm water depression area. Although past efforts to engineer urban stream buffers were plagued by hydraulic failures and maintenance problems, recent experience with similar bioretention areas has been much more positive (Claytor and Schueler, 1996). Consequently, it may be useful to consider elements of bioretention design for the first zone of an urban stream buffer (shallow ponding depths, partial underdrains, drop inlet bypass, etc).

Limitations

Only a handful of studies have measured the ability of stream buffers to remove pollutants from storm water. One limitation is that urban runoff concentrates rapidly on paved and hard-packed turf surfaces and often crosses the buffer as channel flow, effectively shortcutting through the buffer. To achieve optimal pollutant removal, the engineered buffer should be carefully designed with a storm water depression area, grass filter, and forested strip.

Maintenance Considerations

An effective buffer management plan should include establishment, management, and distinctions of allowable and unallowable uses in the buffer zones. Buffer boundaries should be well defined and visible before, during, and after construction. Without clear signs or markers defining the buffer, boundaries become invisible to local governments, contractors, and residents. Buffers designed to capture storm water runoff from urban areas will require more maintenance if the first zone is designated as a bioretention or other engineered depression area.

Effectiveness

The pollutant removal effectiveness of buffers depends on the design of the buffer; while water pollution hazard setbacks are designed to prevent possible contamination from neighboring land uses, they are not designed for pollutant removal during a storm. With vegetated buffers, some pollutant removal studies have shown that they range widely in effectiveness (Table 1). Proper design of buffers can help increase the pollutant removal from storm water runoff (Table 2).

Table 1: Pollutant removal rates in buffer zones

Reference	Buffer Vegetation	Buffer Width (meters)	Total % TSS Removal	Total % Phosphorous Removal	Total % Nitrogen Removal
Dillaha et al., 1989	Grass	4.6–9.1	63–78	57–74	50–67
Magette et al., 1987	Grass	4.6–9.2	72–86	41–53	17–51
Schwer and Clausen, 1989	Grass	26	89	78	76
Lowrance et al., 1983	Native hardwood forest	20–40	–	23	–
Doyle et al., 1977	Grass	1.5	–	8	57
Barker and Young, 1984	Grass	79	–	–	99
Lowrance et al., 1984	Forested	–	–	30–42	85
Overman and Schanze, 1985	Grass	–	81	39	67

Table 2: Factors that enhance/reduce buffer pollutant removal performance

Factors that Enhance Performance	Factors that Reduce Performance
Slopes less than 5%	Slopes greater than 5%
Contributing flow lengths <150 feet.	Overland flow paths over 300 feet
Water table close to surface	Ground water far below surface
Check dams/level spreaders	Contact times less than 5 minutes
Permeable but not sandy soils	Compacted soils
Growing season	Nongrowing season
Long length of buffer or swale	Buffers less than 10 feet
Organic matter, humus, or mulch layer	Snowmelt conditions, ice cover
Small runoff events	Runoff events >2 year event.
Entry runoff velocity less than 1.5 feet/sec	Entry runoff velocity more than 5 feet/sec
Swales that are routinely mowed	Sediment buildup at top of swale
Poorly drained soils, deep roots	Trees with shallow root systems
Dense grass cover, 6 inches tall	Tall grass, sparse vegetative cover

Cost Considerations

Several studies have documented the increase of property values in areas adjacent to buffers. At the same time, the real costs of instituting a buffer program for local government involve the extra staff and training time to conduct plan reviews, and to provide technical assistance, field delineation, construction, and ongoing buffer education programs. To implement a stream buffer program, a community will need to adopt an ordinance, develop technical criteria, and invest in additional staff resources and training. The adoption of a buffer program also requires an investment in training for the plan reviewer and the consultant alike. Manuals, workshops, seminars, and direct technical assistance are needed to explain the new requirements to all the players in the land development business. Lastly, buffers need to be maintained, and resources should include systematic inspection of the buffer network before and after construction and work to increase resident awareness about buffers.

One way to relieve some of the significant financial hardships for developers is to provide flexibility through buffer averaging. Buffer averaging allows developers to narrow the buffer width at some points if the average width of the buffer and the overall buffer area meet the minimum criteria. Variances can also be granted if the developer or landowner can demonstrate severe economic hardship or unique circumstances that make compliance with the buffer ordinance difficult.

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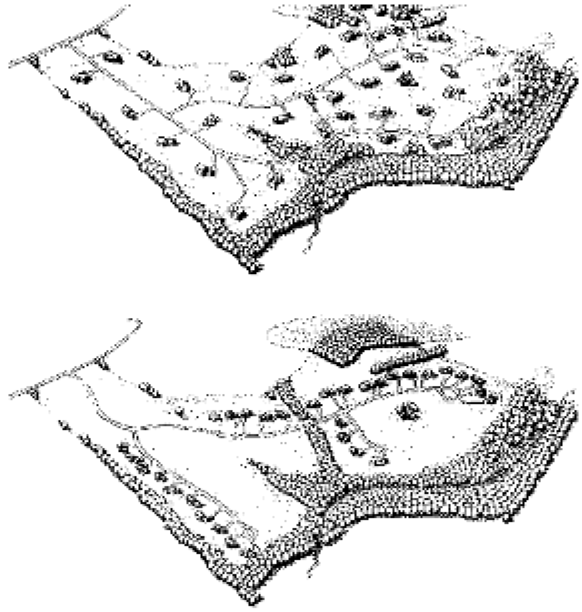
Open Space Design

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Open space design, also known as conservation development or cluster development, is a better site design technique that concentrates dwelling units in a compact area in one portion of the development site in exchange for providing open space and natural areas elsewhere on the site. The minimum lot sizes, setbacks and frontage distances for the residential zone are relaxed in order to create the open space at the site. Open space designs have many benefits in comparison to the conventional subdivisions that they replace: they can reduce impervious cover, storm water pollutants, construction costs, grading, and the loss of natural areas. However, many communities lack zoning ordinances to permit open space development, and even those that have enacted ordinances might need to revise them to achieve greater water quality and environmental benefits.



A site developed using open space design principles (bottom) maintains more undeveloped common space than the conventional development plan (top) (Source: Arendt, 1996)

The benefits of open space design can be amplified when it is combined with other better site design techniques such as narrow streets, open channels, and alternative turnarounds (see Narrower Residential Streets, Eliminating Curbs and Gutters, and Alternative Turnarounds).

Applicability

The codes and ordinances that govern residential development in many communities do not allow developers to build anything other than conventional subdivisions. Consequently, it may be necessary to enact a new ordinance or revise current development regulations to enable developers to pursue this design option. Model ordinances and regulations for open space design can be found on http://www.cwp.org and in *Better Site Design: A Handbook for Changing Development Rules in Your Community* (CWP, 1998).

Open space design is widely applicable to most forms of residential development. The greatest storm water and pollutant reduction benefits typically occur when open space design is applied to residential zones that have larger lots (less than two dwelling units per acre). In these types of large lot zones, a great deal of natural or community open space can be created by shrinking lot sizes. However, open space design may not always be a viable option for high-density residential zones, redevelopment, or infill development, where lots are small to begin with and clustering will yield little open space. In rural areas, open space design may need to be adapted, especially in communities where shared septic fields are not currently allowed by public health authorities.

Open space design can be employed in nearly all geographic regions of the country, with the result of different types of open space being conserved (forest, prairie, farmland, chaparral, or desert).

Siting and Design Conditions

Several site planning techniques have been proposed for designing effective open space developments (Arendt, 1996, and DE DNREC, 1997). Often, a necessary first step is adoption of a local ordinance that allows open space design within conventional residential zones. Such ordinances specify more flexible and smaller lot sizes, setbacks, and frontage distances for the residential zone, as well as minimum requirements for open space and natural area conservation. Other key elements of effective open space ordinances include requirements for the consolidation and use of open space, as well as enforceable provisions for managing the open space on a common basis.

Limitations

A number of real and perceived barriers hinder wider acceptance of open space designs by developers, local governments, and the general public. For example, despite strong evidence to the contrary, some developers still feel that open space designs are less marketable than conventional residential subdivisions. In other cases, developers contend that the review process for open space design is more lengthy, costly, and potentially controversial than that required for conventional subdivisions, and thus, not worth the trouble.

Local governments may be concerned that homeowner associations lack the financial resources, liability insurance, or technical competence to maintain open space adequately. Finally, the general public is often suspicious of cluster or open space development proposals, feeling that they are a "Trojan Horse" for more intense development, traffic, and other local concerns. At the regional level, open space design policies and ordinances need to be carefully constructed and implemented so as not to lead to "leap-frogging," which is the creation of additional development in already built-up areas. An open space development that requires new infrastructure, such as roads, water and sewer lines, and commercial areas, can actually create more imperviousness at the regional level than it saves at the site level.

In reality, many of these misconceptions can be directly addressed through a clear open space ordinance and by providing training and incentives to the development and engineering community. The Natural Resources Defense Council presents several examples of successful conservation-oriented developments in *Stormwater Strategies: Community Responses to Runoff Pollution* (1999).

Maintenance Considerations

Once established, common open space and natural conservation areas must be managed by a responsible party able to maintain the areas in a natural state in perpetuity. Typically, the open space is protected by legally enforceable deed restrictions, conservation easements, and maintenance agreements. In most communities, the authority for managing open space falls to a homeowner or community association or a land trust. Annual maintenance tasks for open space managed as natural areas are almost non-existent, and the annual maintenance cost for managing an acre of natural area is less than $75 (CWP, 1998). It may be useful to develop a habitat plan for natural areas that may require periodic management actions.

Effectiveness

Recent redesign research indicates that open space design can provide impressive pollutant reduction benefits compared to the conventional subdivisions they replace. For example, the Center for Watershed Protection (1998) reported that nutrient export declined by 45 percent to 60 percent when two conventional subdivisions were redesigned as open space subdivisions. Other researchers have reported similar levels of pollutant reductions when conventional subdivisions were replaced by open space subdivisions (Maurer, 1996; DE DNREC, 1997; Dreher and Price, 1994; and SCCCL, 1995). In all cases, the reduction in pollutants was due primarily to the sharp drop in runoff caused by the lower impervious cover associated with open space subdivisions. In the redesign studies cited above, impervious cover declined by an average of 34 percent when open space designs were utilized.

Along with reduced imperviousness, open space designs provide a host of other environmental benefits lacking in most conventional designs. These developments reduce potential pressure to encroach on resource and buffer areas because enough open space is usually reserved to accommodate resource protection areas. As less land is cleared during the construction process, the potential for soil erosion is also greatly diminished. Perhaps most importantly, open space design reserves 25 to 50 percent of the development site in green space that would not otherwise be protected, preserving a greater range of landscapes and habitat "islands" that can support considerable diversity in mammals, songbirds, and other wildlife.

Cost Considerations

Open space developments can be significantly less expensive to build than conventional subdivisions. Most of the cost savings are due to savings in road building and storm water management conveyance costs. In fact, the use of open space design techniques at a residential development in Davis, California, provided an estimated infrastructure construction costs savings of $800 per home (Liptan and Brown, 1996). Other examples demonstrate infrastructure costs savings ranging from 11 to 66 percent. Table 1 lists some of the projected construction cost savings generated by the use of open space redesign at several residential sites.

While open space developments are frequently less expensive to build, developers find that these properties often command higher prices than homes in more conventional developments. Several regional studies estimate that residential properties in open space developments garner premiums that are 5 to 32 percent higher than conventional subdivisions and moreover, sell or lease at an increased rate. In Massachusetts, cluster developments were found to appreciate 12 percent faster than conventional subdivisions over a 20-year period (Lacey and Arendt, 1990). In Atlanta, Georgia, the presence of trees and natural areas measurably increased the residential property tax base (Anderson and Cordell, 1982).

Table 1. Projected construction cost savings for open space designs from redesign analyses

Residential Development	Construction Savings	Notes
Remlik Hall [1]	52%	Includes costs for engineering, road construction, and obtaining water and sewer permits
Duck Crossing [2]	12%	Includes roads, storm water management, and reforestation
Tharpe Knoll [3]	56%	Includes roads and storm water management
Chapel Run [3]	64%	Includes roads, storm water management, and reforestation
Pleasant Hill [3]	43%	Includes roads, storm water management, and reforestation
Rapahannock [2]	20%	Includes roads, storm water management, and reforestation
Buckingham Greene [3]	63%	Includes roads and storm water management
Canton, Ohio [4]	66%	Includes roads and storm water management

Sources: [1] Maurer, 1996; [2] CWP, 1998; [3] DE DNREC, 1997; [4] NAHB, 1986

In addition to being aesthetically pleasing, the reduced impervious cover and increased tree canopy associated with open space development reduce the size and cost of downstream storm water treatment facilities. The resulting cost savings can be considerable, as the cost to treat the quality and quantity of storm water from a single impervious acre can range from $2,000 to a staggering $50,000. The increased open space within a cluster development also provides a greater range of locations for more cost-effective storm water practices. Clearly, open space developments are valuable from an economic as well as an environmental standpoint.

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Urban Forestry

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Urban forestry is the study of trees and forests in and around towns and cities. Since trees absorb water, patches of forest and the trees that line streets can help provide some of the storm water management required in an urban setting. Urban forests also help break up a landscape of impervious cover, provide small but essential green spaces, and link walkways and trails.

Trees can be incorporated into urban landscapes for water quality benefits in addition to aesthetic and shade benefits (Source: Tree City USA, no date)

Successful urban forestry requires a conservation plan for individual trees as well as forest areas larger than 10,000 feet^2. A local forest or tree ordinance is one technique for achieving conservation, and when specific measures to protect and manage these areas are included, urban forests and trees can also help reduce storm water management needs in urban areas.

Applicability

From a stream preservation perspective, it is ideal to retain as much contiguous forest as possible. At the same time, this may not be an option in many urban areas. If forested areas are fragmented, it is ideal to retain the closest fragments together.

In rapidly urbanizing areas, where clearing and grading are important, tree preservation areas should be clearly marked. Delineating lines along a critical root zone (CRZ) rather than a straight line is essential to preserving trees and can help reduce homeowner complaints about tree root interference into sewer or septic lines.

Implementation

The concept of the CRZ is essential to a proper management plan. The CRZ is the area around a tree required for the tree's survival. Determined by the tree size and species, as well as soil conditions, for isolated specimen trees, the CRZ can be estimated as 1-1/2 feet of radial distance for every inch of tree diameter. In larger areas of trees, the CRZ of forests can be estimated at 1 foot of radial distance for every inch of tree diameter, or a minimum of 8 feet.

An urban forestry plan should include measures to establish, conserve, and/or reestablish preservation areas. A forest preservation ordinance is one way to set design standards outlining how a forest should be preserved and managed. The ordinance should outline some basic management techniques and should contain some essential elements. The following is a list of some typical elements of a forest conservation plan:

- A map and narrative description of the forest and the surrounding area that includes topography, soils, streams, current forested and unforested areas, tree lines, critical habitats, and 100-year flood plain.
- An assessment that establishes preservation, reforestation, and afforestation areas.
- A forest conservation map that outlines forest retention areas, reforestation, afforestation, protective devices, limits of disturbance, and stockpile areas.
- A schedule of any additional construction in and around the forest area.
- A specific management plan, including tree and forest protection measures.
- A reforestation and afforestation plan.

An ordinance can also be developed that addresses tree preservation at the site level both during construction and after construction is complete. This type of ordinance can be implemented on a smaller scale and can be integrated with a proposed development's erosion and sediment control and storm water pollution prevention plans, which many communities require of new developments.

American Forests, a non-profit organization dedicated to preserving and restoring forests in the United States, adopted an ecosystem restoration and maintenance agenda in 1999 to assist communities in planning and implementing tree and forest actions to restore and maintain healthy ecosystems and communities (American Forests, 2000). The agenda presents the organization's core values and policy goals as the basis for policy statements and as information to help community-based partners to prepare their own policy statements. Key policy goals include

- Increasing public and private sector investment in ecosystem restoration and maintenance activities
- Promoting an ecosystem workforce through training and apprenticeship programs and new job opportunities
- Building support for innovative monitoring systems to ensure collaborative learning and adaptive management
- Encouraging a "civic science" approach to ecosystem research that respects local knowledge, seeks community participation, and provides accessible information for communities.

Limitations

One of the biggest limitations to urban forestry is development pressure. Ordinances, conservation easements, and other techniques that are designed into a management program can help alleviate future development pressures. The size of the land may also limit the ability to protect individual trees. In these areas, a tree ordinance may be a more practical approach.

Forests may also harbor undesirable wildlife elements including insects and other pests. If forests border houses, this may be a concern for residents.

Maintenance Considerations

Maintenance considerations for urban forests may require fringe landscaping and trash pick-up. By using native vegetation and keeping the area as natural as possible, maintenance efforts can be minimized.

Effectiveness

There are numerous environmental and storm water benefits to urban forestry. These include the absorption of carbon dioxide by trees, reduction of temperature, and provision of habitat for urban wildlife. Urban forests can also act as natural storm water management areas by filtering particulate matter (pollutants, some nutrients, and sediment) and by absorption of water. Urban forestry also reduces noise levels, provides recreational benefits, and increases property values.

Urban forests and trees are known to have numerous environmental benefits, including pollutant removal. Trees can absorb water, pollutant gases, airborne particulates, sediment, nitrogen, phosphorous, and pesticides.

There are numerous economic benefits to urban forests, including proven increases in property values. In addition, by preserving trees and forests, clearing and grading as well as erosion and sediment costs are saved during construction. Maintenance costs are also minimized by keeping areas as natural as possible (Table 1).

Table 1: Annual maintenance costs of different types of green spaces (Adapted from Brown et al., 1998)

Land Use	Approximate Annual Maintenance Costs	Source
Natural Open Space: Only minimum maintenance, trash/debris cleanup	$75/acre/year	NPS, 1995
Lawns: Regular mowing	$270 to $240/acre/year	WHEC, 1992
Passive Recreation	$200/acre/year	NPS, 1995

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Conservation Easements

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Conservation easements are voluntary agreements that allow an individual or group to set aside private property to limit the type or amount of development on their property. The conservation easement can cover all or a portion of a property and can either be permanent or last for a specified time. The easement is typically described in terms of the resource it is designed to protect (e.g., agricultural, forest, historic, or open space easements) and explains and mandates the restrictions on the uses of the particular property. Easements relieve property owners of the burden of managing these areas by shifting responsibility to a private organization (land trust) or government agency better equipped to handle maintenance and monitoring issues.

Conservation easements are thought to make a contribution to protecting water quality, mostly in an indirect way. Land set aside in a permanent conservation easement is land that will have a prescribed set of uses or activities, generally restricting future development.

The location of the land held in a conservation easement may also determine if it will provide water quality benefits. Property along stream corridors and shorelines can act as a vegetated buffer that may filter out pollutants from storm water runoff. The ability of a conservation easement to function as a stream buffer is related to the width of the easement and in what vegetated state the easement is maintained (see Buffer Zones fact sheet).

Applicability

Conservation easements are typically done to preserve agricultural lands and natural areas that are facing development pressure on the suburban-rural fringe. For rapidly urbanizing areas, conservation easements may be a way to preserve open space before land prices make the purchase of land containing important cultural and natural features impractical for governmental agencies with limited budgets. Conservation easements are not often used in ultra-urban areas, due to both the lack of available open space for purchase and the high cost of undeveloped land. In addition, private land trusts may limit the size and type of the land that they are willing to manage as conservation easements.

Implementation

Conservation easements are designed to assure that the land is preserved in its current state long after the original owners no longer control the property. By agreeing to give up or restrict the development rights for a parcel of land, a landowner can guarantee that their property will remain in a prescribed state for perpetuity while receiving tax benefits. Often, state agencies and private land trusts have specific qualifications for a property before they will enter into an easement agreement with land owners. Table 1 contains examples of criteria that are used by private land trusts to determine if a property is worth managing in a conservation easement.

Table 1: Typical criteria that land trusts use to determine feasibility of entering into conservation easement agreement

Criteria	Details
Natural resource value	Does the property provide a critical habitat or important environmental aspects worth preserving?
Uniqueness of the property	Does the property have unique traits worth preserving?
Size of land	Is the land large enough to have a natural resource or conservation value?
Financial considerations	Are funds available to meet all financial obligations?
Perpetuity	Is the conservation agreement a perpetual one?
Land trust's mission	Does the property align with the land trust's mission and the organization's specific criteria?

Conservation easements have been used in all parts of the country, and many private groups, both nationally and locally, exist to preserve natural lands and manage conservation easements. States also use conservation easements and land purchase programs to protect significant environmental features and tracts of open space. Maryland is one state that has been nationally recognized for its programs that provide funding for state and local parks and conservation areas. The state is one of the first to use real estate transfer taxes to pay for land conservation programs. Several programs are funded through this transfer tax of one-half of one percent ($5 per thousand) of the purchase price of a home or land, or other state funding programs. Conservation programs include:

- *Program Open Space*. This program is responsible for acquiring 150,000 acres of open space for state parks and natural resource areas and more than 25,000 acres of local park land. Every county must create a Land Preservation and Recreation Plan that outlines acquisition and development goals in order to receive a portion of the 50 percent that is granted to local governments (MDNR, no date).
- *Maryland Environmental Trust*. This trust is a state-funded agency that helps citizen groups form and operate local land trusts and offers the land trusts technical assistance, training, grants for land protection projects and administrative expenses, and participation in the Maryland Land Trust Alliance (MDNR, 2001a).
- *Rural Legacy Program*. This program is a Smart Growth Initiative that redirects existing state funds into a focused and dedicated land preservation program specifically designed to limit the adverse impacts of sprawl on agricultural lands and natural resources. The program purchases conservation easements for large contiguous tracts of agricultural, forest, and natural areas subject to development pressure, and purchases fee interests in open space where public access and use is needed (MDNR, 2001b).

Regardless of whether a conservation easement is held by a government agency or a private land trust, certain management responsibilities must be addressed by the easement holder. The following is a list of some of these management duties:

- Ensure that the language of the easement is clear and enforceable.
- Develop maps, descriptions and baseline documentation of the property's characteristics.
- Monitor the use of the land on a regular basis.
- Provide information regarding the easement to new or prospective property owners.
- Establish a review and approval process for land activities stipulated in the easement.
- Enforce the restrictions of the easement through the legal system if necessary.
- Maintain property/easement-related records.

Limitations

A number of limitations exist for using conservation easements as a storm water management tool. One is that there is no hard evidence that conservation easements actually do protect water quality. Another is that conservation easements are often not an option in more urbanized areas, where the size, quality, and cost of land can restrict the use of easements. Easements might also not be held in perpetuity, which means that land could still face development pressure in the future. Easements also may not provide for the filtering of pollutants from concentrated flows. More information on the filtering potential of stream buffers can be found in the Buffer Zones fact sheet.

Maintenance Considerations

The responsibility for maintenance of property in a conservation easement depends on the individual agreement with a land trust or agency. While many organizations assume the responsibility for managing and monitoring a property, some land trusts leave maintenance responsibilities to the landowner and act only to monitor that the terms of the easement are met.

Effectiveness

The pollutant removal efficiency of a conservation area will depend on how much is conserved, the techniques used to conserve it, and the specific nature of the easement. Conservation easements are assumed to contribute water quality benefits, but no national studies proving this have been released.

Cost Considerations

Table 2 summarizes the costs of maintaining green spaces with different types of uses.

Table 2: Annual maintenance costs of different types of green space uses (Adapted from CWP, 1998)

Land Use	Approximate Annual Maintenance Costs
Natural open space Only minimum maintenance, trash/debris cleanup	$75/acre/year
Lawns Regular mowing	$270 to $240/acre/year
Passive recreation	$200/acre/year

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Infrastructure Planning

Postconstruction Storm Water Management in New Development and Redevelopment

Description


Developers can design streets and pedestrian paths to maximize convenience and safety while at the same time minimizing impervious surface area (Source: The Rouse Company, no date)

This practice requires changes in the regional growth planning process to contain sprawl development. Sprawl development is the expansion of low-density development into previously undeveloped land. The American Farmland Trust has estimated that the United States is losing about 50 acres an hour to suburban and exurban development (Longman, 1998). This sprawl development requires local governments to extend public services to new residential communities whose tax payments often do not cover the cost of providing those services. For example, in Prince William County, Virginia, officials have estimated that the costs of providing services to new residential homes exceeds what is brought in from taxes and other fees by $1,600 per home (Shear and Casey, 1996).

Infrastructure planning makes wise decisions to locate public services—water, sewer, roads, schools, and emergency services—in the suburban fringe and direct new growth into previously developed areas, discouraging low-density development. Generally, this is done by drawing a boundary or envelope around a community, beyond which major public infrastructure investments are discouraged or not subsidized. Meanwhile, economic and other incentives are provided within the boundary to encourage growth in existing neighborhoods. By encouraging housing growth in areas that are already provided with public services—water, sewer, roads, schools, and emergency services—communities not only save infrastructure development costs, but reduce the impacts of sprawl development on urban streams and water quality.

Sprawl development negatively impacts water quality in several ways. The most significant impact comes from the increase in impervious cover that is associated with sprawl growth. In addition to rooftop impervious area from new development, extension of road systems and additions of paved surface from driveways create an overall increase in imperviousness. This increase in the impervious cover level of an area directly influences local streams and water quality by increasing the volume of storm water runoff. These elevated runoff levels impact urban streams in several ways, including enlarging stream channels, increasing sediment and pollutant loads, degrading stream habitat, and reducing aquatic diversity (Schueler, 1995). Sprawl has been reported to generate 43 percent more runoff that contains three times greater sediment loads than traditional development (SCCCL, 1995).

Sprawl development influences water quality in other ways. This type of development typically occurs in areas not served by centralized sewer or water services. For example, over 80 percent of the land developed in the state of Maryland in the last decade has been outside the sewer and water "envelope." This requires new housing developments to use septic systems or another form of on-site wastewater disposal to treat household sewage. These on-site treatment systems can represent a significant source of nutrients and bacteria that affect both surface waters and groundwater. More information about septic systems is contained in the fact sheets in both the Illicit Discharge Detection and Elimination Category and the Pollution Prevention Category.

Applicability

Sprawl development occurs in all regions of the country and has recently become the subject of many new programs to counteract its impacts. These programs seldom focus on the water quality implications of sprawl growth, instead concentrating on economic and transportation issues. Even so, methods such as infrastructure planning can reduce the impact of new development. Promoting the infill and redevelopment of existing urban areas in combination with other better site design techniques (see the other fact sheets in this category) will decrease impervious cover levels and lessen the amount of pollution discharged to urban streams.

Siting and Design Conditions

Various techniques have been used to manage urban growth while conserving resources. Although none of these techniques specifically concentrates on infrastructure planning, each of the techniques recognizes that directing growth to areas that have been previously developed or promoting higher density development in areas where services exist prevents sprawl development and helps communities to mitigate the water quality impacts of economic growth. Among the techniques that have been used are:

- *Urban Growth Boundaries*. This planning tool establishes a dividing line that defines where a growth limit is to occur and where agricultural or rural land is to be preserved. Often, an urban services area is included in this boundary that creates a zone where public services will not be extended.

- *Infill/Community Redevelopment*. This practice encourages new development in unused or underutilized land in existing urban areas. Communities may offer tax breaks or other economic incentives to developers to promote the redevelopment of properties that are vacant or damaged.

The State of Maryland has been one of the states that has recently passed legislation to control growth. This "Smart Growth" legislation allows the State to direct its programs and funding to support locally-designated growth areas and protect rural and natural areas. The central component of this legislative package is the "Priority Funding Areas" legislation that limits most state infrastructure funding and economic development program monies to areas that local governments designate for growth and that meet guidelines for intended use, availability of plans for sewer and water systems, and permitted residential density (MOP, no date).

The other bills in the legislative package also support development of existing areas and preservation of undeveloped land. A brownfields program encourages revitalization of existing neighborhoods and industrial areas and establishes a brownfield revitalization incentive program that provides grants and low-interest loans to fund brownfield redevelopment. A new "Live Near Your Work" pilot program supports this effort by providing cash contributions to workers buying homes in certain older neighborhoods. The "Rural Legacy Program" spurs preservation of undeveloped land by providing financial resources for the protection of farm and forest lands from development and for the conservation of these essential rural resources from development.

Limitations

Intense development of existing areas can create a new set of challenges for storm water program managers. Storm water management solutions are often more difficult and complex in ultra-urban areas than in suburban areas. The lack of space for structural storm water controls and the high cost of available land where structural controls could be installed are just two problems that program managers will face in managing storm water in intensely developed areas.

Infrastructure planning is often done on a regional scale and requires a cooperative effort between all the communities within a given region in order to be successful. Phase II program managers will need to develop lines of communication with other state and local agencies and community leaders to ensure that infrastructure plans direct growth to those areas that will have the least impacts on watersheds and water quality.

Effectiveness

The effectiveness of infrastructure planning at protecting water quality is currently unknown. Although studies exist detailing the economic benefits of infrastructure planning, how this translates to storm water pollutant reductions is difficult if not impossible to calculate. However, a relationship does exist between impervious cover levels and urban stream characteristics, and one can assume that tools such as infrastructure planning that help control imperviousness have a positive impact on water quality.

Compact development benefits program managers in numerous ways. One benefit is that compact development can preserve prime agricultural land and sensitive areas while reducing costly construction of new infrastructure (Pelley, 1997). Less new land developed translates into less need for new infrastructure and public services.

Cost Considerations

The economic benefits of reducing costly construction of new infrastructure and providing new services can be quite substantial. The following is a list of examples of the projected savings of limiting sprawl through managed growth (APA, no date):

- New Jersey's plan for managed growth will save the state $700 million in road costs, $562 million in sewer and water costs, $178 million in school costs, and up to $380 million in operating costs per year.
- Fifteen years of continued sprawl would cost Maryland $10 billion more than a more compact pattern of growth.
- A 1989 Florida study demonstrated that planned, concentrated growth would cost the taxpayer 50 percent to 75 percent less than continued sprawl.
- The Cities of Minneapolis-St. Paul will spend $3.1 billion by the year 2020 for new water and sewer services to accommodate sprawl.
- Since 1980 the City of Fresno, California, has added $56 million in yearly revenues but has added $123 million in service costs.

Other studies have found that planned development consumes about 45 percent less land and costs 25 percent less for roads, 15 percent less for utilities, 5 percent less for housing, and 2 percent less for other fiscal impacts (Burchell and Listokin, 1995, as cited in Pelley, 1997).

The control of sprawl development through legislation and "Smart Growth" programs is currently being implemented in a number of states and counties across the U.S. As these programs mature and begin to influence development patterns in urban areas, local governments should begin to see the positive impacts of condensed growth on the aquatic environment and water quality of local streams.

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Narrower Residential Streets

Postconstruction Storm Water Management in New Development and Redevelopment

Description

A narrow street in a residential neighborhood. Cars can be parked in driveways or along the road shoulder

This better site design practice promotes the use of narrower streets to reduce the amount of impervious cover created by new residential development and, in turn, reduce the storm water runoff and associated pollutant loads. Currently, many communities require wide residential streets that are 32, 36, and even 40 feet wide. These wide streets provide two parking lanes and two moving lanes, but provide much more parking than is actually necessary. In many residential settings, streets can be as narrow as 22 to 26 feet wide without sacrificing emergency access, on-street parking or vehicular and pedestrian safety. Even narrower access streets or shared driveways can be used when only a handful of homes need to be served. However, developers often have little flexibility to design narrower streets, as most communities require wide residential streets as a standard element of their local road and zoning standards. Revisions to current local road standards are often needed to promote more widespread use of narrower residential streets.

Applicability

Narrower streets can be used in residential development settings that generate 500 or fewer average daily trips (ADT), which is generally about 50 single family homes, and may sometimes also be feasible for streets that are projected to have 500 to 1,000 ADT. However, narrower streets are not feasible for arterials, collectors, and other street types that carry greater traffic volumes or are not expected to have a constant traffic volume over time.

In most communities, existing local road standards will need to be modified to permit the use of narrower streets. Several communities have successfully implemented narrower streets, including Portland, OR; Bucks County, PA; Boulder, CO; and throughout New Jersey. In addition, there are numerous examples of communities where developers have successfully narrowed private streets within innovative subdivisions.

Siting and Design Conditions

Residential street design requires a careful balancing of many competing objectives: design, speed, traffic volume, emergency access, parking, and safety. Communities that want to change their road standards to permit narrower streets need to involve all the stakeholders who influence street design in the revision process. Several excellent references on narrow street design are provided at the end of this fact sheet.

Limitations

A number of real and perceived barriers hinder wider acceptance of narrower streets at the local level. Advocates for narrower streets will need to respond to the concerns of many local agencies and the general public. Some of the more frequent concerns about narrower streets are listed below.

- *Inadequate On-Street Parking*. Recent research and local experience have demonstrated that narrow streets can easily accommodate residential parking demand. A single family home typically requires 2 to 2.5 parking spaces. In most residential zones, this parking demand can be easily satisfied by one parking lane on the street and driveways.

- *Car and Pedestrian Safety.* Recent research indicates that narrow streets have lower accident rates than wide streets. Narrow streets tend to lower the speed of vehicles and act as traffic calming devices.

- *Emergency Access.* When designed properly, narrower streets can easily accommodate fire trucks, ambulances and other emergency vehicles.

- *Large Vehicles.* Field tests have shown that school buses, garbage trucks, moving vans, and other large vehicles can generally safely negotiate narrower streets, even when cars are parked on both sides of the street. In regions with high snowfall, streets may need to be slightly wider to accommodate snowplows and other equipment.

- *Utility Corridors*. It is often necessary to place utilities underneath the street rather than in the right of way.

In addition, local communities may lack the authority to change road standards when the review of public roads is retained by state agencies. In these cases, street narrowing can be accomplished only on private streets (i.e., maintained by residents rather than a local or state agency).

Maintenance Considerations

Narrower streets should slightly reduce road maintenance costs for local communities, since they present a smaller surface area to maintain and repair.

Effectiveness

Since streets constitute the largest share of impervious cover in residential developments (about 40 to 50 percent), a shift to narrower streets can result in a 5-to 20-percent overall reduction in impervious area for a typical residential subdivision (Schueler, 1995). As nearly all the pollutants deposited on street surfaces or trapped along curbs are delivered to the storm drain system during storm events, this reduced imperviousness translates directly into less storm water runoff and pollutant loadings from the development. From the standpoint of storm water quality, residential streets rank as a major source area for many storm water pollutants, including sediment, bacteria, nutrients, hydrocarbons, and metals (Bannerman, 1994).

Cost Considerations

Narrower streets cost less to build than wider streets. Considering that the cost of paving a road averages $15 per square yard, shaving even a mere four feet from existing street widths can yield cost savings of more than $35,000 per mile of residential street. In addition, since narrower streets produce less impervious cover and runoff, additional savings can be realized in the reduced size and cost of downstream storm water management facilities.

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Eliminating Curbs and Gutters

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Developers can eliminate curbs and gutters to disconnect impervious surfaces and promote infiltration of storm water on vegetated areas (such as this grass-lined channel in a residential neighborhood)

This better site design practice involves promoting the use of grass swales as an alternative to curbs and gutters along residential streets. Curbs and gutters are designed to quickly convey runoff from the street to the storm drain and, ultimately, to the local receiving water. Consequently, curbs and gutters provide little or no removal of storm water pollutants. Indeed, curbs often act as a pollutant trap where deposited pollutants are stored until they are washed out in the next storm. Many communities require curb and gutters as a standard element of their road sections, and discourage the use of grass swales. Revisions to current local road and drainage regulations are needed to promote greater use of grass swales along residential streets, in the appropriate setting. The storm water management and pollutant removal benefits of grass swales are documented in detail in the Grassed Swales fact sheet.

Applicability

The use of engineered swales in place of curbs and gutters should be encouraged in low- and medium-density residential zones where soils, slope and housing density permit. However, eliminating curbs and gutters is generally not feasible for streets with high traffic volume or extensive on-street parking demand (i.e., commercial and industrial roads), nor is it a viable option in arid and semi-arid climates where grass cannot grow without irrigation. Moreover, the use of grass swales may not be permitted by current local or state street and drainage standards.

Siting and Design Conditions

A series of site factors must be evaluated to determine whether a grass swale is a viable replacement for curbs and gutters at a particular site.

Contributing drainage area. Most individual swales cannot accept runoff from more than 5 acres of contributing drainage area, and typically serve 1–2 acres each.

Slope. Swales generally require a minimum slope of 1 percent and a maximum slope of 5 percent.

Soils. The effectiveness of swales is greatest when the underlying soils are permeable (hydrologic soil groups A and B). The swale may need more engineering if soils are less permeable.

Water Table. Swales should be avoided if the seasonally high water table is within 2 feet of the proposed bottom of the swale.

Development Density. The use of swales is often difficult when development density becomes more intense than four dwelling units per acre, simply because the number of driveway culverts increases to the point where the swale essentially becomes a broken-pipe system. Typically, grass swales are designed with a capacity to handle the peak flow rate from a 10-year storm, and fall below erosive velocities for a 2-year storm.

Limitations

A number of real and perceived limitations hinder the use of grass swales as an alternative to curb and gutters:

- *Snowplow operation can be more difficult without a defined road edge*. However, on the plus side, roadside swales increase snow storage at the road edge, and smaller snowplows may be adequate.

- *The pavement edge along the swale can experience more cracking and structural failure, increasing maintenance costs.* The potential for pavement failure at the road/grass interface can be alleviated by "hardening" the interface with grass pavers or geo-synthetics placed beneath the grass. Other options include placing a low-rising concrete strip along the pavement edge.

- *The shoulder and open channel will require more maintenance*. In reality, maintenance requirements for grass channels are generally comparable to those of curb and gutter systems. The major requirements involve turf mowing, debris removal, and periodic inspections.

- *Some grass swales can have standing water, which make them difficult to mow, and can cause nuisance problems such as odors, discoloration, and mosquitoes*. In reality, grass channels are not designed to retain water for any appreciable period of time, and the potential for snakes and other vermin can be minimized by frequent mowing.

Other concerns involve fears about utility installation and worries that the grass edge along the pavement will be torn up by traffic and parking. While utilities will need to be installed below the paved road surface instead of the right of way, most other concerns can frequently be alleviated through the careful design and integration of the open channels along the residential street. (Consult the Grassed Swales fact sheet for details on design variations that can reduce these problems.)

Maintenance Considerations

The major maintenance requirement for grass swales involves mowing during the growing season, a task usually performed by homeowners. In addition, sediment deposits may need to be removed from the bottom of the swale every ten years or so, and the swale may need to be tilled and re-seeded periodically. Occasionally, erosion of swale side slopes may need to be stabilized. The overall maintenance burden of grass swales is low in relation to other storm water practices, and is usually within the competence of the individual homeowner. The only major maintenance problem that might arise pertains to "problem" swales that have standing water and are too wet to mow. This particular problem is often alleviated by the installation of an underground storm drain system.

Effectiveness

Under the proper design conditions, grass swales can be effective in removing pollutants from urban storm water (Schueler, 1996). More information on the pollutant removal capability of various grass swale designs can be found in the Grassed Swales fact sheet.

Cost Considerations

Engineered swales are a much less expensive option for storm water conveyance than the curb and gutter systems they replace. Curbs and gutters and the associated underground storm sewers frequently cost as much as $36 per linear foot, which is roughly twice the cost of a grass swale (Schueler, 1995, and CWP, 1998). Consequently, when curbs and gutters can be eliminated, the cost savings can be considerable.

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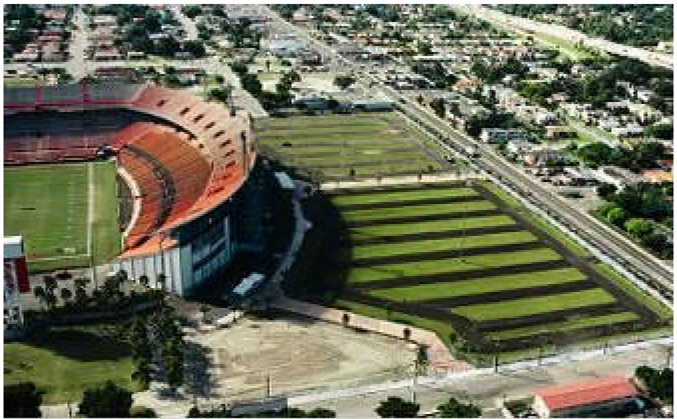
Green Parking

Postconstruction Storm Water Management in New Development and Redevelopment

Description



A green parking lot at the Orange Bowl in Miami, Florida (Source: Invisible Structures, no date)

Green parking refers to several techniques applied together to reduce the contribution of parking lots to the total impervious cover in a lot. From a storm water perspective, application of green parking techniques in the right combination can dramatically reduce impervious cover and, consequently, the amount of storm water runoff. Green parking lot techniques include setting maximums for the number of parking lots created, minimizing the dimensions of parking lot spaces, utilizing alternative pavers in overflow parking areas, using bioretention areas to treat storm water, encouraging shared parking, and providing economic incentives for structured parking.

Applicability

All of the green parking techniques can be applied in new developments and some can be applied in redevelopment projects, depending on the extent and parameters of the project. In urban areas, application of some techniques, like encouraging shared parking and providing economic incentives for structured parking, can be very practical and necessary. Commercial areas can have excessively high parking ratios, and application of green parking techniques in various combinations can dramatically reduce the impervious cover of a site.

Implementation

Many parking lot designs result in far more spaces than actually required. This problem is exacerbated by a common practice of setting parking ratios to accommodate the highest hourly parking during the peak season. By determining average parking demand instead, a lower maximum number of parking spaces can be set to accommodate most of the demand. Table 1 provides examples of conventional parking requirements and compares them to average parking demand.

Table 1: Conventional minimum parking ratios (Source: ITE, 1987; Smith, 1984; Wells, 1994)

Land Use	Parking Requirement		Actual Average Parking Demand
	Parking Ratio	Typical Range	
Single family homes	2 spaces per dwelling unit	1.5–2.5	1.11 spaces per dwelling unit
Shopping center	5 spaces per 1000 ft^2 GFA	4.0–6.5	3.97 per 1000 ft^2 GFA
Convenience store	3.3 spaces per 1000 ft^2 GFA	2.0–10.0	--
Industrial	1 space per 1000 ft^2 GFA	0.5–2.0	1.48 per 1000 ft^2 GFA
Medical/ dental office	5.7 spaces per 1000 ft^2 GFA	4.5–10.0	4.11 per 1000 ft^2 GFA
GFA = Gross floor area of a building without storage or utility spaces.			

Another green parking lot technique is to minimize the dimensions of the parking spaces. This can be accomplished by reducing both the length and width of the parking stall. Parking stall dimensions can be further reduced if compact spaces are provided. While the trend toward larger sport utility vehicles (SUVs) is often cited as a barrier to implementing stall minimization technique, stall width requirements in most local parking codes are much larger than the widest SUVs (CWP, 1998).

Utilizing alternative pavers is also an effective green parking technique. They can replace conventional asphalt or concrete in both new developments and redevelopment projects. Alternative pavers can range from medium to relatively high effectiveness in meeting storm water quality goals. The different types of alternative pavers include gravel, cobbles, wood mulch, brick, grass pavers, turf blocks, natural stone, pervious concrete, and porous asphalt. In general, alternate pavers require proper installation and more maintenance than conventional asphalt or concrete. For more specific information on alternate pavers, refer to the Alternative Pavers fact sheet.

Bioretention areas can effectively treat storm water leaving a parking lot. Storm water is directed into a shallow, landscaped area and temporarily detained. The runoff then filters down through the bed of the facility and is infiltrated into the subsurface or collected into an underdrain pipe for discharge into a stream or another storm water facility. Bioretention facilities can be attractively integrated into landscaped areas and can be maintained by commercial landscaping firms. For detailed design specifications of bioretention areas, refer to the Bioretention fact sheet.

Shared parking in mixed-use areas and structured parking also are green parking techniques that can further reduce the conversion of land to impervious cover. A shared parking arrangement could include usage of the same parking lot by an office space that experiences peak parking demand during the weekday with a church that experiences parking demands during the weekends and evenings. Costs may dictate the usage of structured parking, but building upward or downward can help minimize surface parking.

Limitations

Some limitations to applying green parking techniques include applicability, cost, and maintenance. For example, shared parking is only practical in mixed use areas, and structured parking may be limited by the cost of land versus construction. Alternative pavers are currently only recommended for overflow parking because of the considerable cost of maintenance. Bioretention areas increase construction costs.

The pressure to provide excessive parking spaces can come from fear of complaints as well as requirements of bank loans. These factors can pressure developers to construct more parking than necessary and present possible barriers to providing the greenest parking lot possible.

Effectiveness

Applied together, green parking techniques can effectively reduce the amount of impervious cover, help to protect local streams, result in storm water management cost savings, and visually enhance a site. Proper design of bioretention areas can help meet storm water management and landscaping requirements while keeping maintenance costs at a minimum.

Utilizing green parking lots can dramatically reduce the amount of impervious cover created. The level of the effectiveness depends on how much impervious cover is reduced as well as the combination of techniques utilized to provide the greenest parking lot. While the pollutant removal rates of bioretention areas have not been directly measured, their capability is considered comparable to a dry swale, which removes 91 percent of total suspended solids, 67 percent of total phosphorous, 92 percent of total nitrogen, and 80–90 percent of metals (Claytor and Schueler, 1996).

An excellent example of the multiple benefits of rethinking parking lot design is the Fort Bragg vehicle maintenance facility parking lot in North Carolina (NRDC, 1999). This redesign reduced impervious cover by 40 percent, increased parking by 20 percent, and saved $1.6 million (20 percent) on construction costs over the original, conventional design. Stormwater management features, such as detention basins located within grassed islands and an onsite drainage system that took advantage of existing sandy soils, were incorporated into the parking lot design as well.

Cost Considerations

Setting maximums for parking spaces, minimizing stall dimensions, and encouraging shared parking can result in considerable construction cost savings. At the same time, implementing green parking techniques can also reduce storm water management costs.

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Alternative Turnarounds

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Rather than having a fully paved cul-de-sac bulb, site designers can incorporate pervious circles with vegetation that reduce the site's overall impervious area

Alternative turnarounds are designs for end-of-street vehicle turnaround that replace cul-de-sacs and reduce the amount of impervious cover created in residential neighborhoods. Cul-de-sacs are local access streets with a closed circular end that allows for vehicle turnarounds. Many of these cul-de-sacs can have a radius of more than 40 feet. From a storm water perspective, cul-de-sacs create a huge bulb of impervious cover, increasing the amount of storm water runoff. For this reason, reducing the size of cul-de-sacs through the use of alternative turnarounds or eliminating them altogether can reduce the amount of impervious cover created at a site.

Numerous alternatives create less impervious cover than the traditional 40-foot cul-de-sac. These alternatives include reducing cul-de-sacs to a 30-foot radius and creating hammerheads, loop roads, and pervious islands in the cul-de-sac center.

Applicability

Alternative turnarounds can be applied in the design of residential, commercial, and mixed-use developments. Combined with alternative pavers, green parking, curb elimination, and other techniques, the total reduction to site impervious cover can be dramatic, reducing the amount of storm water runoff from the site. With proper designs, much of the remaining storm water can be treated on site.

Implementation

Sufficient turnaround area is a significant factor to consider in the design of cul-de-sacs. In particular, the types of vehicles entering into the cul-de-sac should be considered. Fire trucks, service vehicles, and school buses are often cited as examples for increased turning radii. However, research shows that some fire trucks are designed for smaller turning radii. In addition, many new larger service vehicles are designed using a tri-axle, and school buses usually do not enter individual cul-de-sacs.

Implementation of alternative turnarounds will also have to address local regulations and marketing issues. Communities may have specific design criteria for cul-de-sacs and other alternative turnarounds. Also, although cul-de-sacs are often featured as highly marketable, actual research on market preference is not widely available.

Limitations

Local regulations often dictate requirements for turnaround radii, and some of the alternatives may not be allowed by local codes. In addition, marketing perceptions may also dictate designs, particularly in residential areas. While changing local codes is no small effort, by initiating a local site planning roundtable, communities can change some of these regulations through a cluster ordinance or through a collective effort to review local codes to promote better site design.

Maintenance Considerations

If islands are constructed as part of a turnaround, these areas will need to be maintained. Kept as a natural area, the costs could be minimal. Bioretention areas will also require maintenance. The other options create less asphalt to repave, and maintenance will remain the same and cost less.

Effectiveness

In comparisons of several different turnaround options, hammerheads were found to create the least amount of impervious cover, as shown in Table 1.

Table 1. Impervious cover created by each turnaround option (Schueler, 1995)

Turnaround Option	Impervious Area (square feet)
40-foot radius	5,024
40-foot radius with island	4,397
30-foot radius	2,826
30-foot radius with island	2,512
Hammerhead	1,250

Costs

Since alternative turnarounds reduce the amount of impervious cover created, construction savings can be an incentive (asphalt costs $0.50–$1.00 per square foot in materials alone). Bioretention is estimated at $6.40 per cubic foot, and while it costs more than providing naturally vegetated areas, it can help reduce overall storm water management costs.

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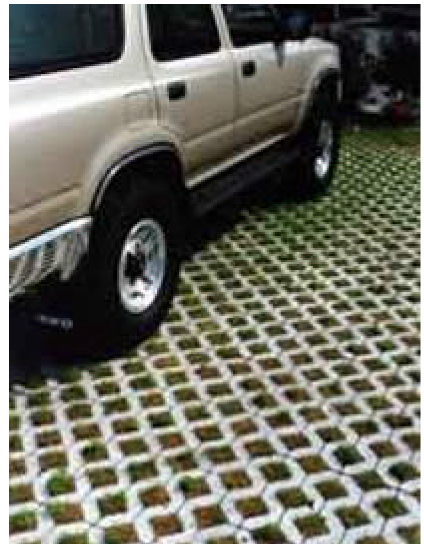
Alternative Pavers

Postconstruction Storm Water Management in New Development and Redevelopment

Description



One type of alternative paver consists of a concrete lattice structure for support with grass growing in the void spaces (Source: Lo Gioco Landscaping, Inc., no date)

Alternative pavers are permeable surfaces that can replace asphalt and concrete and can be used for driveways, parking lots, and walkways. From a storm water perspective, this is important because alternative pavers can replace impervious surfaces, creating less storm water runoff. The two broad categories of alternative pavers are paving blocks and other surfaces, including gravel, cobbles, wood, mulch, brick, and natural stone. While porous pavement is an alternative paver, as an engineered storm water management practice it is discussed in detail in the Porous Pavement fact sheet.

Paving Blocks

Paving blocks are concrete or plastic grids with gaps between them. Paving blocks make the surface more rigid and gravel or grass planted inside the holes allows for infiltration. Depending on the use and soil types, a gravel layer can be added underneath to prevent settling and allow further infiltration.

Other Alternative Surfaces

Gravel, cobbles, wood, and mulch also allow varying degrees of infiltration. Brick and natural stone arranged in a loose configuration allow for some infiltration through the gaps. Gravel and cobbles can be used as driveway material, and wood and mulch can be used to provide walking trails.

Applicability

Alternative pavers can replace conventional asphalt or concrete in parking lots, driveways, and walkways. At the same time, traffic volume and type can limit application. For this reason, alternative pavers for parking are recommended only for overflow areas. In residential areas, alternative surfaces can be used for driveways and walkways, but are not ideal for areas that require handicap accessibility.

Siting and Design Criteria

Accessibility, climate, soil type, traffic volume, and long-term performance should be considered, along with costs and storm water quality controls, when choosing paving materials. Use of alternative pavers in cold climates will require special consideration, as snow shovels are not practical for many of these surfaces. Sand is particularly troublesome if used with paving blocks, as the sand that ends up between the blocks cannot effectively wash away or be removed.

In addition, salt used to de-ice can also infiltrate directly into the soil and cause potential ground water pollution.

Soil types will affect the infiltration rates and should be considered when using alternative pavers. Clayey soils (D soils) will limit the infiltration on a site. If ground water pollution is a concern, use of alternative pavers with porous soils should be carefully considered.

The durability and maintenance cost of alternative pavers also limits use to low-traffic-volume areas. At the same time, alternative pavers can abate storm water management costs. Used in combination with other better-site-design techniques, the cumulative effect on storm water can be dramatic.

Limitations

Alternative pavers are not recommended for high-traffic volumes for durability reasons. Access for wheelchairs is limited with alternative pavers. In addition, snow removal is difficult since plows cannot be used, sand can cause the system to clog, and salt can be a potential pollutant.

Maintenance Considerations

Alternative pavers require periodic maintenance, and costs increase when the permeable surface must be restored.

Effectiveness

The most obvious benefit of utilizing alternative pavers includes reduction or elimination of other storm water management techniques. Applied in combination with other techniques such as bioretention and green parking, pollutant removal and storm water management can be further improved. (see Bioretention and Green Parking fact sheets for more information.)

Alternative pavers all provide better water quality improvement than conventional asphalt or concrete, and the range of improvement depends on the type of paver used. Table 1 provides a list of pavers and the range of water quality improvement achievable by different types of alternative pavers.

Table 1. Water quality improvement of various pavers (Source: BASMAA, 1997)

Material	Water Quality Effectiveness
Conventional Asphalt/ Concrete	Low
Brick (in a loose configuration)	Medium
Natural Stone	Medium
Gravel	High
Wood Mulch	High
Cobbles	Medium

Cost Considerations

The range of installation and maintenance costs of various pavers is provided in Table 2. Depending on the material used, installation costs can be higher or lower for alternative pavers than for conventional asphalt or concrete, but maintenance costs are almost always higher.

Table 2. Installation and maintenance costs for various pavers (Source: BASMAA, 1997)

Material	Installation Cost	Maintenance Cost
Conventional Asphalt/Concrete	Medium	Low
Brick (in a loose configuration)	High	Medium
Natural Stone	High	Medium
Gravel	Low	Medium
Wood Mulch	Low	Medium
Cobbles	Low	Medium

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BMP Inspection and Maintenance

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Regular inspection and maintenance of storm water best management practices is important to ensure that the practices are functioning properly and to remove trash and organic debris

To maintain the effectiveness of postconstruction storm water control best management practices (BMPs), regular inspection of control measures is essential. Generally, inspection and maintenance of BMPs can be categorized into two groups—expected routine maintenance and nonroutine (repair) maintenance. Routine maintenance refers to checks performed on a regular basis to keep the BMP in good working order and aesthetically pleasing. In addition, routine inspection and maintenance is an efficient way to prevent potential nuisance situations (odors, mosquitoes, weeds, etc.), reduce the need for repair maintenance, and reduce the chance of polluting storm water runoff by finding and correcting problems before the next rain.

In addition to maintaining the effectiveness of storm water BMPs and reducing the incidence of pests, proper inspection and maintenance is essential to avoid the health and safety threats inherent in BMP neglect (Skupien, 1995). The failure of structural storm water BMPs can lead to downstream flooding, causing property damage, injury, and even death.

Applicability

Under the proposed Storm Water Phase II rule, owners and operators of small municipal separate storm sewer system (MS4) facilities would be responsible for implementing BMP inspection and maintenance programs and having penalties in place to deter infractions (USEPA, 1999). All storm water BMPs should be inspected for continued effectiveness and structural integrity on a regular basis. Generally, all BMPs should be checked after each storm event in addition to these regularly scheduled inspections. Scheduled inspections will vary among BMPs. Structural BMPs such as storm drain drop inlet protection may require more frequent inspection to ensure proper operation. During each inspection, the inspector should document whether the BMP is performing correctly, any damage to the BMP since the last inspection, and what should be done to repair the BMP if damage has occurred.

Siting and Design Considerations

In the case of vegetative or other infiltration BMPs, inspection of storm water management practices following a storm event should occur after the expected drawdown period for a given

BMP. This allows the inspector to see whether detention and infiltration devices are draining correctly.

Inspection checklists should be developed for use by BMP inspectors. Checklists might include each BMP's minimum performance expectations, design criteria, structural specifications, date of implementation, and expected life span. In addition, the maintenance requirements for each BMP should be listed on the inspection checklist. This will aid the inspector in determining whether a BMP's maintenance schedule is adequate or needs revision. Also, a checklist will help the inspector determine renovation or repair needs.

Limitations

Routine maintenance materials such as shovels, lawn mowers, and fertilizer may be easily obtained on short notice with little effort. Unfortunately, not all materials that may be needed for emergency structural repairs are obtained with such ease. Thought should be given to stockpiling essential materials in case immediate repairs must be made to safeguard against property loss and to protect human health.

Maintenance Considerations

It is important that routine maintenance and nonroutine repair of storm water BMPs be done according to schedule or as soon as a problem is discovered. Because many BMPs are rendered ineffective for runoff control if not installed and maintained properly, it is essential that maintenance schedules are maintained and repairs are made promptly. In fact, some cases of BMP neglect can have detrimental effects on the landscape and increase the potential for erosion. However, "routine" maintenance, such as mowing grasses, should be flexible enough to accommodate the fluctuations in need based on relative weather conditions. For example, more harm than good may be caused by mowing during an extremely dry period or immediately following a storm event.

Effectiveness

The effectiveness of BMP inspection will be a function of the familiarity of the inspector with each particular BMP's location, design specifications, maintenance procedures, and performance expectations. Documentation should be kept regarding the dates of inspection, findings, and maintenance and repairs that result from the findings of an inspector. Such records are helpful in maintaining an efficient inspection and maintenance schedule and providing evidence of ongoing inspection and maintenance.

Because maintenance work for storm water BMPs is usually not technically complicated (mowing, removal of sediment, etc.), workers can be drawn from a large labor pool. As structural BMPs increase in their sophistication, however, more specialized maintenance training might be needed to sustain BMP effectiveness.

Cost Considerations

Mowing of vegetated and grassed areas may be the costliest routine maintenance consideration (WEF, 1998). Management practices using relatively weak materials (such as filter fabric and wooden posts) may mean more frequent replacement and therefore increased costs. The use of more sturdy materials (such as metal posts) where applicable may increase the life of certain BMPs and reduce replacement cost. However, the disposal requirements of all materials should be investigated before BMP implementation to ensure proper handling after the BMP has become ineffective or when it needs to be disposed of after the site has reached final stabilization. Table 1 shows maintenance costs, specific activities, and schedules for several postconstruction runoff BMPs.

Table 1. Maintenance costs, activities, and schedules for urban management practices (Adapted from CWP, 1998)

Type of Practice	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Detention/ Retention Practices	Ponds/ wetlands	3%–6%	\$3,000 to \$6,000	• Cleaning and removal of debris after major storm events; (>f rainfall) • Harvest vegetation when a 50% reduction in the original open water surface area occurs • Repair of embankment and side slopes • Repair of control structure	Annual or as needed
				• Removal of accumulated sediment from forebays or sediment storage areas when 60% of the original volume has been lost	5-year cycle
				• Removal of accumulated sediment from main cells of pond once 50% of the original volume has been lost	20-year cycle
	Dry Ponds	~1%	\$1,200	See above	
	Wetlands	~2%	\$3,800	See above	
Infiltration Facilities	Infiltration Trench	5%–20%	\$2,300 to \$9,000	• Cleaning and removal of debris after major storm events; (>2" rainfall) • Mowing and maintenance of upland vegetated areas • Sediment cleanout • Repair or replacing of stone aggregate • Maintenance of inlets and outlets	Annual or as needed
				• Removal of accumulated sediment from forebays or sediment storage areas when 50% of the original volume has been lost	4-year cycle
	Infiltration Basin	1%–10%	\$150–\$1,500	• Cleaning and removal of debris after major storm events; (>2" rainfall) • Mowing and maintenance of upland vegetated areas • Sediment cleanout	Annual or as needed
				• Removal of accumulated sediment from forebays or sediment storage areas when 50% of the original volume has been lost	3- to 5-year cycle

Table 1. (continued)

Type of Practice	Management Practice	Annual Maintenance Cost (% of Construction Cost)	Maintenance Cost for a "Typical" Application	Maintenance Activity	Schedule
Filtration Practices	Sand Filters	11%–13%	$2,200	• Removal of trash and debris from control openings • Repair of leaks from the sedimentation chamber or deterioration of structural components • Removal of the top few inches of sand, and cultivation of the surface, when filter bed is clogged	Annual or as needed
				• Clean out of accumulated sediment from filter bed chamber once depth exceeds approximately ½ inch, or when the filter layer will no longer draw down within 24 hours • Clean out of accumulated sediment from sedimentation chamber once depth exceeds 12 inches	3- to 5-year cycle
	Dry Swales, Grassed Channels, Biofilters	5%–7%	$200 to $2,000	• Mowing and litter/debris removal • Stabilization of eroded side slopes and bottom • Nurtient and pesticide use management • Dethatching swale bottom and removal of thatching • Discing or aeration of swale bottom	Annual or as needed
				• Scraping swale bottom and removal of sediment to restore original cross section and infiltration rate • Seeding or sodding to restore ground cover (use proper erosion and sediment control)	5-year cycle
	Filter Strips	$320/acre (maintained)	$1,000	• Mowing and litter/debris removal • Nutrient and pesticide use management • Aeration of soil on the filter strip • Repair of eroded or sparse grass areas	Annual or as needed
	Bioretention	5%–7%	$3,000 to $4,000	• Repair of erosion areas • Mulching of void areas • Removal and replacement of all dead and diseased vegetation • Watering of plant material	Biannual or as needed
				• Removal of mulch and application of a new layer	Annual

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Ordinances for Postconstruction Runoff

Postconstruction Storm Water Management in New Development and Redevelopment

Description

The management of storm water runoff from sites after the construction phase is vital to controlling the impacts of development on urban water quality. The increase in impervious surfaces such as rooftops, roads, parking lots, and sidewalks due to land development can have a detrimental effect on aquatic systems. Heightened levels of impervious cover have been associated with stream warming and loss of aquatic biodiversity in urban areas. Runoff from impervious areas can also contain a variety of pollutants that are detrimental to water quality, including sediment, nutrients, road salts, heavy metals, pathogenic bacteria, and petroleum hydrocarbons.

An ordinance promotes the public welfare by guiding, regulating, and controlling the design, construction, use, and maintenance of any development or other activity that disturbs or breaks the topsoil or results in the movement of earth on land. The goal of a storm water management ordinance for postconstruction runoff is to limit surface runoff volumes and reduce water runoff pollutant loadings.

Applicability

These ordinances are applicable to all major subdivisions in a municipality. The size of the development to which postconstruction storm water management runoff control applies varies, but many communities opt for a size limit of 5,000 square feet or more. Applicability should be addressed in more detail in the ordinance itself. It is important to note that all plans must be reviewed by local environmental protection officials to ensure that established water quality standards will be maintained during and after development of the site and that postconstruction runoff levels are consistent with any local and regional watershed plans.

Several resources are available to assist in developing an ordinance. EPA's (2000) postconstruction model ordinance web site (*http://www.epa.gov/nps/ordinance/postcons.htm*) provides a model ordinance and examples of programs currently being implemented. In addition, the Stormwater Managers Resource Center (*http://www.stormwatercenter.net*), which was created by the Center for Watershed Protection (no date) and sponsored by the U.S. Environmental Protection Agency, provides information to storm water management program managers in Phase II communities to assist in meeting the requirements of the National Pollutant Discharge Elimination System Phase II regulations.

Siting and Design Considerations

The purpose of the postconstruction ordinance is to establish storm water management requirements and controls to protect and safeguard the general health, safety, and welfare of the public residing in watersheds within a jurisdiction. The following paragraphs provide the general language and concepts that can be included in your ordinance.

General Provisions

This section should identify the purpose, objectives, and applicability of the ordinance. The size of the development to which postconstruction runoff controls apply varies, but many communities opt for a size limit of 5,000 square feet or more. This section can also contain a discussion of the development of a storm water design manual. This manual can include a list of acceptable storm water treatment practices and may include the specific design criteria for each storm water practice. In addition, local communities should select the minimum water quality performance standards they will require for storm water treatment practices, and place them in the design manual.

Definitions

It is important to define the terms that will be used throughout the ordinance to assist the reader and prevent misinterpretation.

Permit Procedures and Requirements

This section should identify the permit required; the application requirements, procedures, and fees; and the permit duration. The intent of the permit should be to ensure that no activities that disturb the land are issued permits prior to review and approval. Communities may elect to issue a storm water management permit separate from any other land development permits required, or, as in this ordinance, to tie the issuing of construction permits to the approval of a final storm water management plan.

Waivers to Storm Water Management Requirements

This section should discuss the process for requesting a waiver and to whom this waiver would be applicable. Alternatives such as fees or other provisions for those requesting a waiver should be addressed as well.

General Performance Criteria for Storm Water Management

The performance criteria that must be met should be discussed in this section. The performance criteria can include the following:

- All sites must establish storm water practices to control the peak flow rates of storm water discharge associated with specified design storms and reduce the generation of storm water.

- New development may not discharge untreated storm water directly into a jurisdictional wetland or local waterbody without adequate treatment.

- Annual groundwater recharge rates must be maintained by promoting infiltration through the use of structural and non-structural methods.

- For new development, structural sewage treatment plants must be designed to remove a certain percentage of the average annual postdevelopment total suspended solids (TSS) load.

Basic Storm Water Management Design Criteria

Rather than place specific storm water design criteria into an ordinance, it is often preferable to fully detail these requirements in a storm water design manual. This approach allows specific design information to be changed over time as new information or techniques become available without requiring the formal process needed to change ordinance language. The ordinance can then require those submitting any development application to consult the current storm water design manual for the exact design criteria for the storm water management practices appropriate for their site. Topics in the manual can include minimum control requirements, site design feasibility, conveyance issues, pretreatment requirements, and maintenance agreements.

Requirements for Storm Water Management Plan Approval

The requirements for a storm water management plan to be approved should be addressed in this section. This can be accomplished by including a submittal checklist in the storm water design manual. A checklist is particularly beneficial because changes in submittal requirements can be made as needed without needing to revisit and later revise the original ordinance.

Construction Inspection

This section should include information on the notice of construction commencement, as-built plans, and landscaping and stabilization requirements.

Maintenance and Repair of Storm Water Facilities

Maintenance agreements, failure to maintain practices, maintenance covenants, right-of-entry for inspection, and records of installation and maintenance activities should be addressed in this section.

Enforcement and Penalties

This section should include information regarding violations, notices of violation, stop work orders, and civil and criminal penalties.

Limitations

Site inspections are required for a postconstruction storm water ordinance to be effective. In addition, an adequate staff must be available to review permit applications and proposed plans.

Maintenance Considerations

The operation and maintenance language in a storm water ordinance can ensure that designs facilitate easy maintenance and that regular maintenance activities are completed. In the "Maintenance and Repair of Storm Water Facilities" section of your ordinance, it is important to include language regarding a maintenance agreement, failure to maintain practices, maintenance covenants, right-of-entry for inspection, and records of installation and maintenance activities.

Effectiveness

If a storm water management ordinance for existing development is properly implemented and enforced, the community can effectively achieve the following:

- Minimize increases in storm water runoff from any development to reduce flooding, siltation, and streambank erosion and to maintain the integrity of stream channels.

- Minimize increases in nonpoint source pollution caused by storm water runoff from development that would otherwise degrade local water quality.

- Minimize the total annual volume of surface water runoff that flows from any specific site during and following development so as not to exceed the predevelopment hydrologic regime to the maximum extent practicable.

- Reduce storm water runoff rates and volumes, soil erosion, and nonpoint source pollution, wherever possible, through storm water management controls and ensure that these management controls are properly maintained and pose no threat to public safety.

Cost Considerations

Municipalities that implement and enforce postconstruction ordinances must budget for the drafting and enforcement of the regulation.

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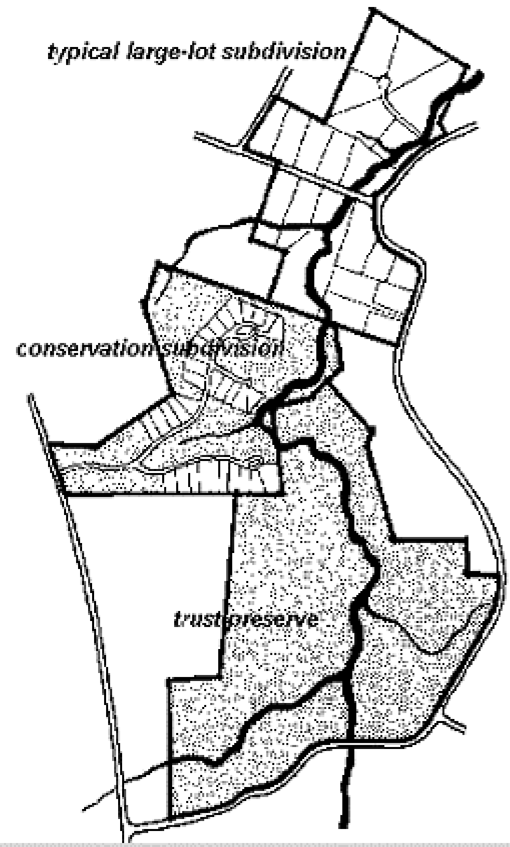
Zoning

Postconstruction Storm Water Management in New Development and Redevelopment

Description

Zoning is a classification scheme for land use planning. Zoning can serve numerous functions and can help mitigate storm water runoff problems by facilitating better site designs. By correctly applying the right zoning technique, development can be targeted into specific areas, limiting development in other areas and providing protection for the most important land conservation areas.

There are numerous types of zoning techniques for better site design, including watershed-based zoning, overlay zoning, floating zones, incentive zoning, performance zoning, urban growth boundaries, large lot zoning, infill/community redevelopment, transfer of development rights, and limiting infrastructure extensions. Table 1 describes each of these zoning techniques and its utility.



Property boundaries differ widely between traditional large-lot zoning, which maximizes the acreage of individual properties, and conservation zoning, which maximizes the amount of shared open space (Source: Arendt, 1996)

Applicability

The type of zoning to apply will depend on management goals. If water or land quality is a primary goal of the zoning technique, then watershed-based zoning can provide a comprehensive approach. At the same time, incentive zoning, performance zoning, and transfer of development rights can be used as protection measures for specific conservation areas.

Implementation

Watershed-Based Zoning: Watershed-based zoning can employ a mixture of land use and zoning options to achieve desired results. A watershed-based zoning approach should include the following nine steps:

- Conduct a comprehensive stream inventory.
- Measure current levels of impervious cover.
- Verify impervious cover/stream quality relationships.
- Project future levels of impervious cover.

Table 1. Zoning techniques (Source: Caraco et al., 1998)

Land Use Planning Technique	**Description**	**Utility as a Watershed Protection Technique**
Watershed-Based Zoning	Watershed and subwatershed boundaries are the foundation for land use planning.	Protects receiving water quality on the subwatershed scale by relocating development out of particular subwatersheds.
Overlay Zoning	Superimposes additional regulations or specific development criteria within specific mapped districts.	Requires development restrictions or allows alternative site design techniques in specific areas.
Impervious Overlay Zoning	Specific overlay zoning that limits total impervious cover within mapped districts.	Protects receiving water quality at both the subwatershed and site level.
Floating Zones	Applies a special zoning district without identifying the exact location until land owner specifically requests the zone.	Obtains proffers or other watershed protective measures that accompany specific land uses within the district.
Incentive Zoning	Applies bonuses or incentives to encourage creation of amenities or environmental protection.	Encourages development within a particular subwatershed or to obtain open space in exchange for a density bonus at the site level.
Performance Zoning	Specifies a performance requirement that accompanies a zoning district.	Requires additional levels of performance within a subwatershed or at the site level.
Urban Growth Boundaries	Establishes a dividing line that defines where a growth limit is to occur and where agricultural or rural land is to be preserved.	Used in conjunction with natural watershed or subwatershed boundaries to protect specific water bodies.
Large Lot Zoning	Zones land at very low densities.	Decreases impervious cover at the site or subwatershed level, but may have an adverse impact on regional or watershed imperviousness.
Infill/Community Redevelopment	Encourages new development and redevelopment within existing developed areas.	Used in conjunction with watershed-based zoning or other zoning tools to restrict development in sensitive areas and foster development in areas with existing infrastructure.
Transfer of Development Rights (TDRs)	Transfers potential development from a designated "sending area" to a designated "receiving area."	Used in conjunction with watershed-based zoning to restrict development in sensitive areas and encourage development in areas capable of accommodating increased densities.
Limiting Infrastructure Extensions	A conscious decision is made to limit or deny extending infrastructure (such as public sewer, water, or roads) to designated areas to avoid increased development in these areas.	A temporary method to control growth in a targeted watershed or subwatershed. Usually delays development until the economic or political climate changes.

- Classify subwatersheds-based on stream management "templates" and current impervious cover.
- Modify master plans/zoning to correspond to subwatershed impervious cover targets and other management strategies identified in Subwatershed Management Templates.
- Incorporate management priorities from larger watershed management units such as river basins or larger watersheds (see discussion later in this fact sheet).
- Adopt specific watershed protection strategies for each subwatershed.
- Conduct long-term monitoring over a prescribed cycle to assess watershed status.

<u>Overlay Zoning:</u> The advantage of overlay zones is that specific criteria can be applied to isolated areas without the threat of being considered spot zoning. Overlay districts are not necessarily restricted by the limits of the underlying base zoning. An overlay zone may take up only a part of an underlying zone or may even encompass several underlying zones. Often the utilization of an overlay zone is optional.

<u>Impervious Overlay Zoning:</u> This type of overlay zoning limits future impervious areas. The environmental impacts of future impervious cover are estimated and a limit is set on the maximum imperviousness within a given planning area. Site development proposals are then reviewed in the context of an imperviousness cap. Subdivision layout options must then conform to the total impervious limit of the planning area.

<u>Floating Zones:</u> Normally, a parcel of land will not qualify for the application of the floating zone district unless it is large enough to allow the buffering of its development from the surrounding area. It is important to note that the existence of a floating zone district does not automatically grant rezoning to each landowner whose property complies with the prescribed conditions. Each property owner must have his or her application for rezoning reviewed and approved by the local governing body to determine if it is consistent with a comprehensive development plan.

<u>Incentive Zoning</u>: This planning technique relies on bonuses or incentives for developers to encourage the creation of certain amenities or land use designs. A developer is granted the right to build more intensively on a property or given some other bonus in exchange for an amenity or a design that the community considers beneficial. Developers stand to gain an increase in profits from the more intensive use of the property, while a community might use incentive zoning to promote more compact development, encourage open space designs, or generate other desired amenities such as trails, parks, or totlots.

<u>Performance Zoning:</u> Performance zoning is a flexible approach that has been employed in a variety of fashions in several different communities across the country. Some performance factors include traffic or noise generation limits, lighting requirements, storm water runoff quality and quantity criteria, protection of wildlife and vegetation, and even architectural style criteria.

<u>Urban Growth Boundaries</u>: Urban growth boundaries are sometimes called development service districts and include areas where public services are already provided (e.g., sewer, water, roads, police, fire, and schools). The delineation of the boundary is very important. Several important issues to consider in establishing an urban growth boundary include the following:

- Public facilities and services must be nearby and/or can be provided at reasonable cost and in a specific time frame.
- A sufficient amount of land to meet projected growth over the planning period must be provided.
- A mix of land uses must be provided.
- The potential impact of growth within the boundary on existing natural resources should be analyzed.
- The criteria for defining the boundary needs to be fair and should consider natural features (versus man-made features) wherever possible. The use of watershed boundaries as the urban growth boundary is one such natural feature.

Large Lot Zoning: Although large lot zoning does tend to reduce the impervious cover and therefore the amount of storm water runoff at a particular location, it also spreads development over vast areas. The road networks required to connect these large lots can actually increase the total amount of imperviousness created for each dwelling unit (Schueler, 1995). In addition, large lot zoning contributes to regional sprawl. Sprawl-like development increases the expense of providing community services such as fire protection, water and sewer systems, and school transportation.

Infill/Community Redevelopment: Infill and redevelopment can be employed in either large or small projects. Some of the existing impediments to more widespread implementation of these types of projects include the existing condition of a potential redevelopment site in terms of environmental constraints, the restrictive nature of many land use regulations, and pressing social and economic issues. Local governments may need to modify local zoning or building codes to make infill and redevelopment a more inviting attraction to developers. In addition, citizen involvement has been demonstrated to be a vital catalyst for leveraging funding or revising codes. Furthermore, lending institutions must be progressive in their view of funding infill and redevelopment projects. One possibility is to partner with local governments or community organizations.

Transfer of Development Rights (TDRs): The principle of TDRs is based on the premise that ownership of land entails certain property rights. While some of these rights may be restricted by zoning, building codes, and environmental constraints, landowners are "entitled" to use their land for the "highest and best use." TDRs are based on a market-driven incentive program where it is possible to sell development potential (zoned density) without buying or selling land. Landowners in preservation areas are compensated for lost development potential , while conventional down-zoning deprives landowners of this potential value.

Limitations

Some zoning techniques may be limited by economic and political acceptance and should be evaluated on these criteria as well as storm water management goals.

Maintenance Considerations

Some maintenance issues to consider for the long term are the following:

- What are the most economically and politically acceptable zoning technique(s) that can be used to shift or reduce impervious cover among the subwatersheds?

- How accurate are the estimates of the amount and location of future impervious cover in the watershed? Are better projections needed?

- Will future increases in impervious cover create unacceptable changes to a watershed and/or subwatershed?

- Which subwatersheds appear capable of absorbing future growth in impervious cover?

Effectiveness

There are numerous case studies of performance-based zoning used in different communities. Some of these examples are summarized in Table 2.

Table 2. Case examples of performance-based zoning (Source: Porter et al., 1991)

Location	Performance Zoning Provisions	Notes
Fort Collins, Colorado	Planned Unit Development (PUD) options are applied to all parcels in city. Developers may choose conventional zoning or the optional PUD. PUD proposals must meet a point value for an absolute criterion and a relative criterion.	Applications are discussed at a conceptual stage where suggestions are made to improve scores. The local planning board has quite a bit of latitude to use discretion to require special conditions.
Largo, Florida	The Land Use Plan defines uses and densities. Four overlay "policy"districts (environmental conservation, management, redevelopment, and downtown) define general standards and prohibited uses. Each land use within a policy district falls into a one of three classes (allowable, allowable with special mitigating measures, or prohibited).	A variety of uses are permitted within the 4 policy districts when applying the special mitigating measures. The city also has a five-tiered system of review and approval that facilitates fast reviews for many common applications and a more involved process for projects that require mitigation.
Hardin County, Kentucky	The land development ordinance allows agricultural and single family uses by right. All other uses must be evaluated by a three-step process. At the first step, the agricultural and development potential is evaluated using a point system. If the site scores a minimum threshold value, than it moves onto the second step, a compatibility assessment. The final step involves typical review of subdivision standards and requirements.	The program places a special emphasis on preserving agricultural uses. The process involves a unique feature that calls on citizen consensus for each step. This decision making process might be considered highly discretionary, but with a widespread interest by most Hardin County citizens in seeing development proceed, there have been few complaints.
Bath Charter Township, Michigan	The township's ordinance provides five zoning districts: two traditional districts for rural, low-density residential; and three applied to existing settlements/expected development corridor. These three districts allow a range of uses either "by right" or with special permits for certain uses.	The ordinance is a compromise between complex, inflexible zoning and no zoning at all. The process allows for extensive review and individual decisions for individual controversial cases.

Table 2. (continued)

Location	Performance Zoning Provisions	Notes
Buckingham Township, Pennsylvania	The ordinance contains typical zoning districts but provides cluster and performance standard development provisions. It aims to preserve natural resources by clustering housing on the least environmentally sensitive areas.	Development of cluster and performance standards are "by rights," and as such, do not require public hearings. The sensitivity of natural areas makes the zoning more flexible in unrestricted areas but less flexible than most conventional zoning in placing restrictions for protecting natural areas.
Duxbury, Massachusetts	Two new categories of development (planned developments and cluster) were created in addition to existing traditional zoning. Both types are allowed in different portions of the town under a special permit process.	Termed "impact zoning," the ordinance aimed to create incentives for developers to build more diverse and environmentally sensitive housing. Developers are choosing standard subdivisions over the optional techniques to avoid lengthy and complex reviews.

Cost Considerations

Subwatershed planning for better site design zoning involves many costs. Mapping, photography, delineations, and involving the public are some of the items typically in such a budget (Table 3).

Table 3. Unit prices for subwatershed planning (Adapted from CWP, 1998)

Budget Item	Estimated Unit Cost	Assumptions
Aerial Photography	$500 per photo	Includes aerial flyover and developing of one color photograph.
Base Mapping	$500	For Subwatershed Management Map using USGS 7.5 minute Quad. Sheet. Includes, subwatershed delineation, overlaying land use, monitoring stations, and transportation routes.
Base Mapping	$5,000	For Aquatic Corridor Management Map, using aerial topography at 2' contour interval. Includes, aerial topography at 1" = 200', locating existing utilities, floodplain, wetlands, and riparian cover from existing maps (no field walk and no topo. survey control).
Floodplain Delineation	$5,000	Detailed analysis beyond FEMA, cross-sections plotted at 1000 ft on-center, topo spot-checked, road crossings evaluated, includes report, assumes flow data are available.
Geographic Information System (GIS)—start-up	$15,000	High end work station and software (e.g., ARC/INFO), includes approx. 2 weeks of training for operator. Does not include data layers
GIS—Obtain or Digitize Data Layers	–	Data layers include impervious cover, topography (5' C.I.), zoning, utilities, vegetative cover (broad categories)
Impervious Cover Measurement—Actual	$3,000	Uses digital orthophotography, impervious layer clipped at subwatershed boundary, algorithm to calculate impervious area

Table 3. (continued)

Budget Item	Estimated Unit Cost	Assumptions
Impervious Cover Estimation—Land Use	$600	Uses land use designations or zoning and measured areas compared against tables, requires review of aerial photo (not included) to estimate build-out.
Impervious Cover Projection—Based on Future Land Use	$800	Uses zoning or master plan and measured areas compared against tables, requires assessment of future build-out
Public Attitude Survey	$15,000 per survey	1000 homes contacted by telephone, includes survey questionnaire preparation and data analysis.
Stakeholder Involvement Program	$15,000	Plan and hold four public and four community meetings, direct mail to 20,000 people, staff time and direct expenses included.

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